Numix Meeting

Using MIPP

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Introduction

Using MIPP:

- to study the Hadron Production (HP) comparing with the thin target data and see the effect on the flux.
- to combine in a comprehensive strategy with thin target data, low nu, beam fit and Nu-e.

Today, I am going to show some results from the first bullet.

Thin Target HP Reweighting

- Cascades leading to ν are tabulated at generation. Save kinematics & material.
- In analysis, interactions reweighted as σ(data)/σ(MC).
- Includes correction for beam attenuation in the target.

Datasets Used

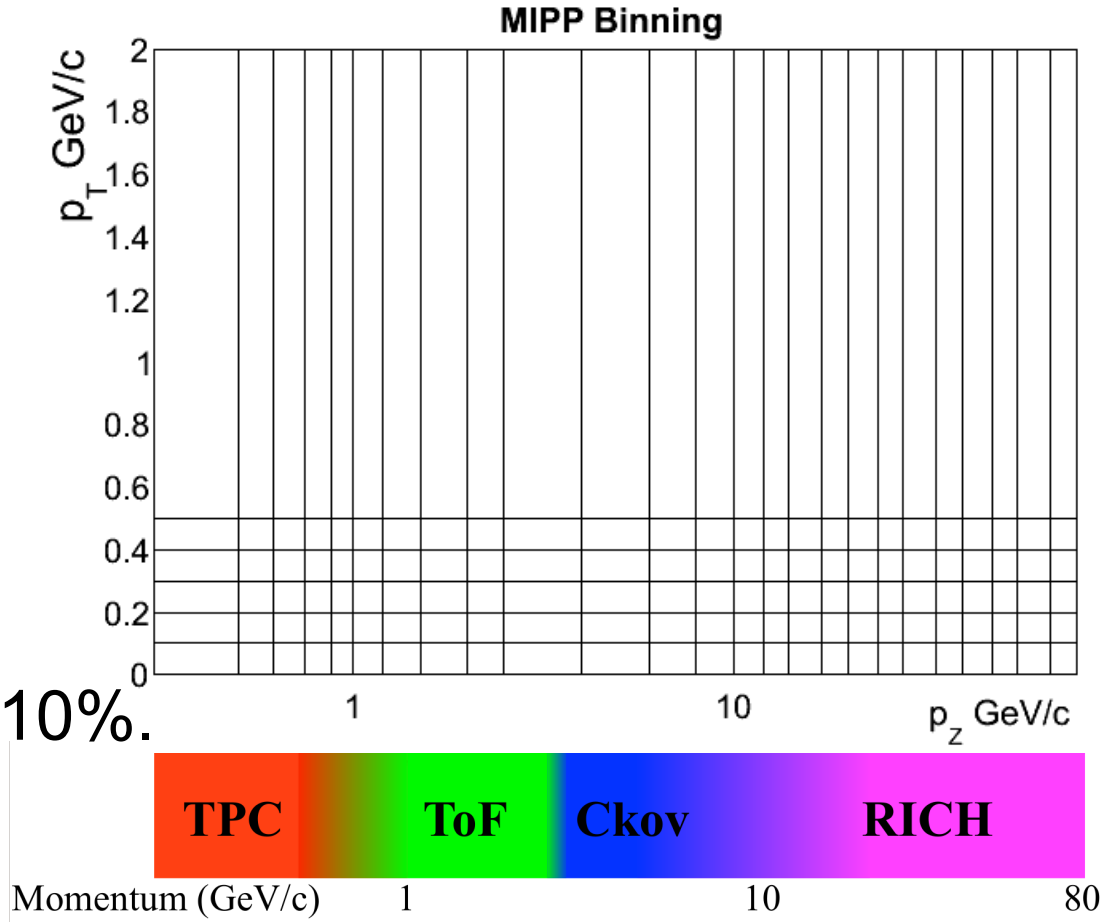
- NA49 pC @ 158 GeV (p_T dependence)
  - $\pi^{\pm}$ production for xF < 0.5 *[Eur.Phys.J. C49 (2007) 897]*
  - $K^{\pm}$ production for xF < 0.2 *[G. Tinti Ph.D. thesis]*
  - p production for xF<0.9 [*Eur.Phys.J. C73 (2013) 2364]*
- Barton pC @ 100 GeV (0.3< p_T <0.5 GeV/c)
  - $\pi^{\pm}$ production for xF < 0.5 *[Phys.Rev. D27 (1983) 2580]*
- MIPP pC @ 120 GeV
  - K/π + NA49 extend kaon coverage to xF < 0.5 *[Phys.Rev. D27 (1983) 2580]*

- Weights applied for 12<$p_{incident}$<120 GeV/c, scaled by Fluka and checked by comparing to NA61 pC @ 31 GeV *[Phys.Rev. C84 (2011)034604].*
- Interactions on Al, Fe, He and Air are treated as if on C.

NuMI replica MIPP data

- Yields of π^+ and π^- in:

$$0.3 < p_Z < 80\ GeV/c$$
$$0 < p_T < 2\ GeV/c$$



- Low bin errors: between 5%-10%.

- Combines different detectors to maximize coverage.

- Data published (arXiv:1404.5882v1). A parametrized version was presented in Jon Paley's W&C (see backup slide).

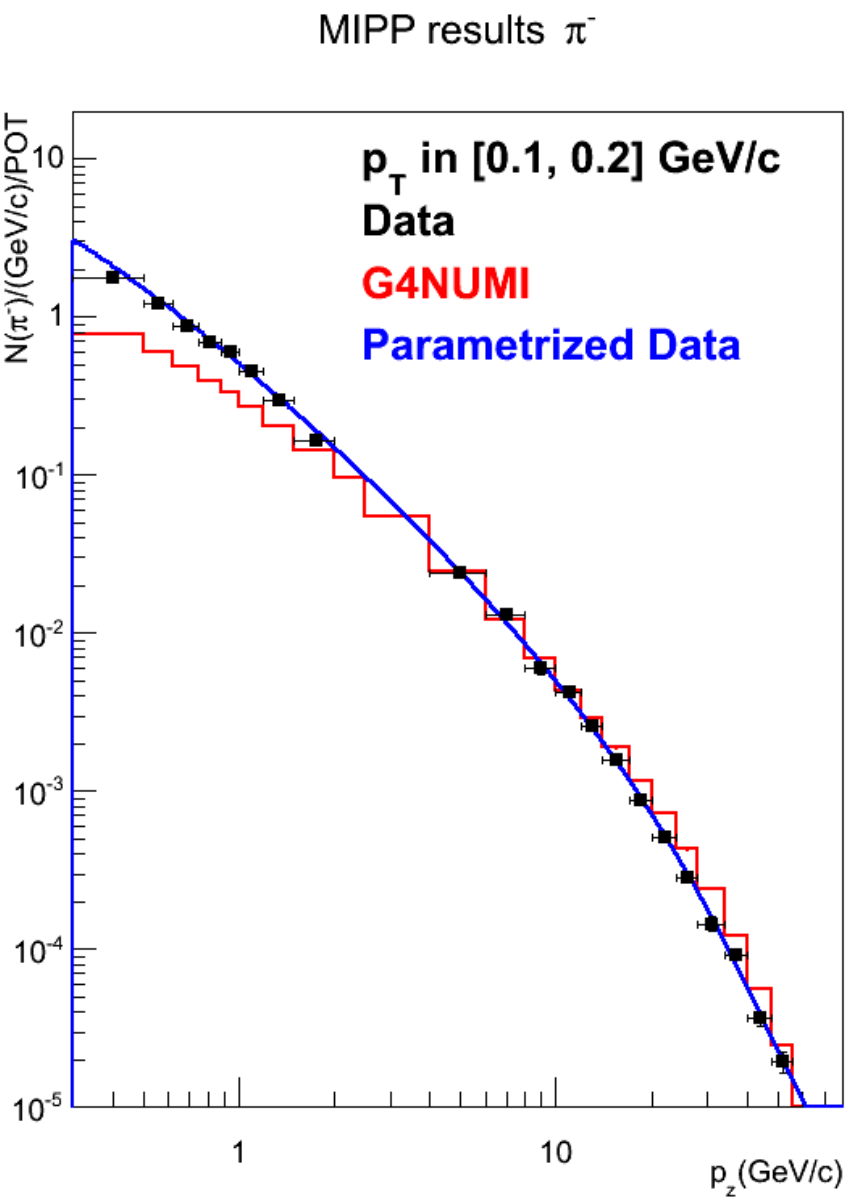
Comparison of FTFP to MIPP Replica

MIPP Data – Parametrization – g4numi comparison

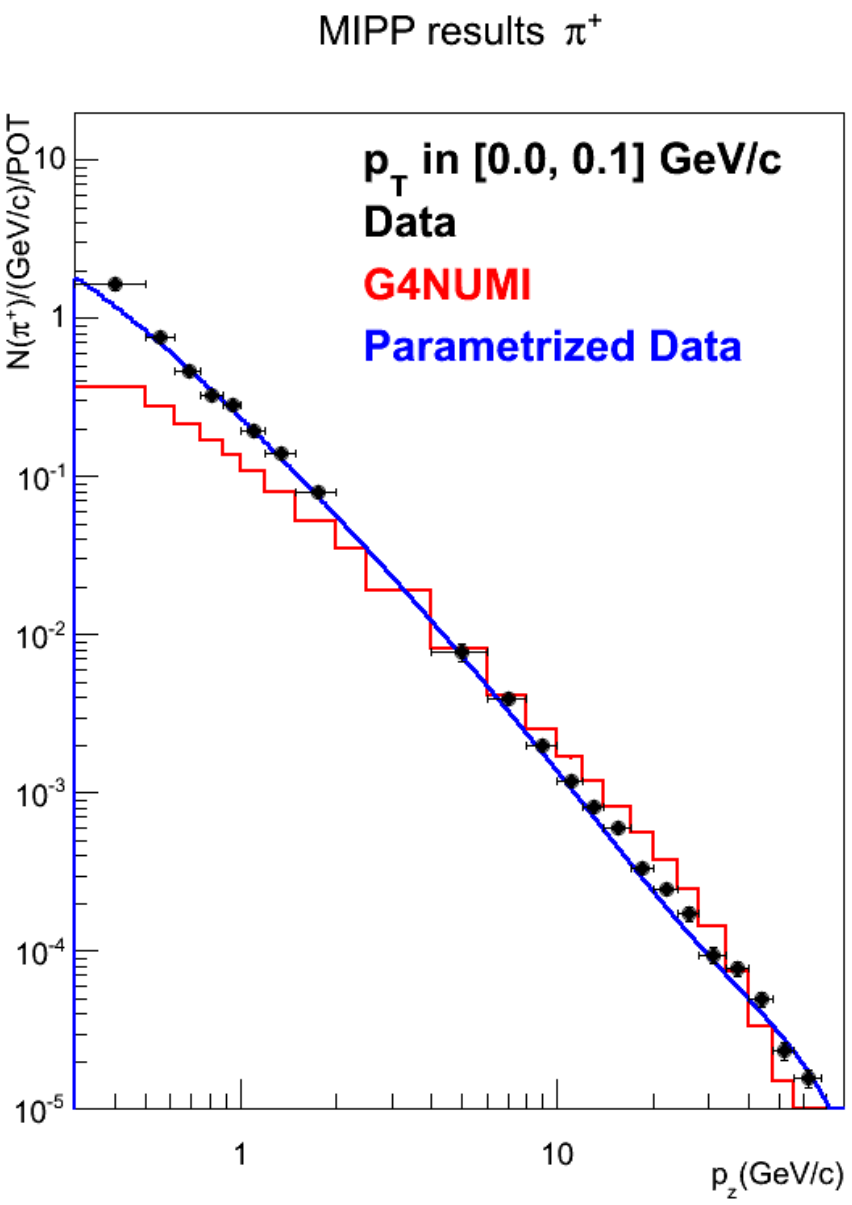
- Y axis integrated p_T yield divided by p_z bin size.

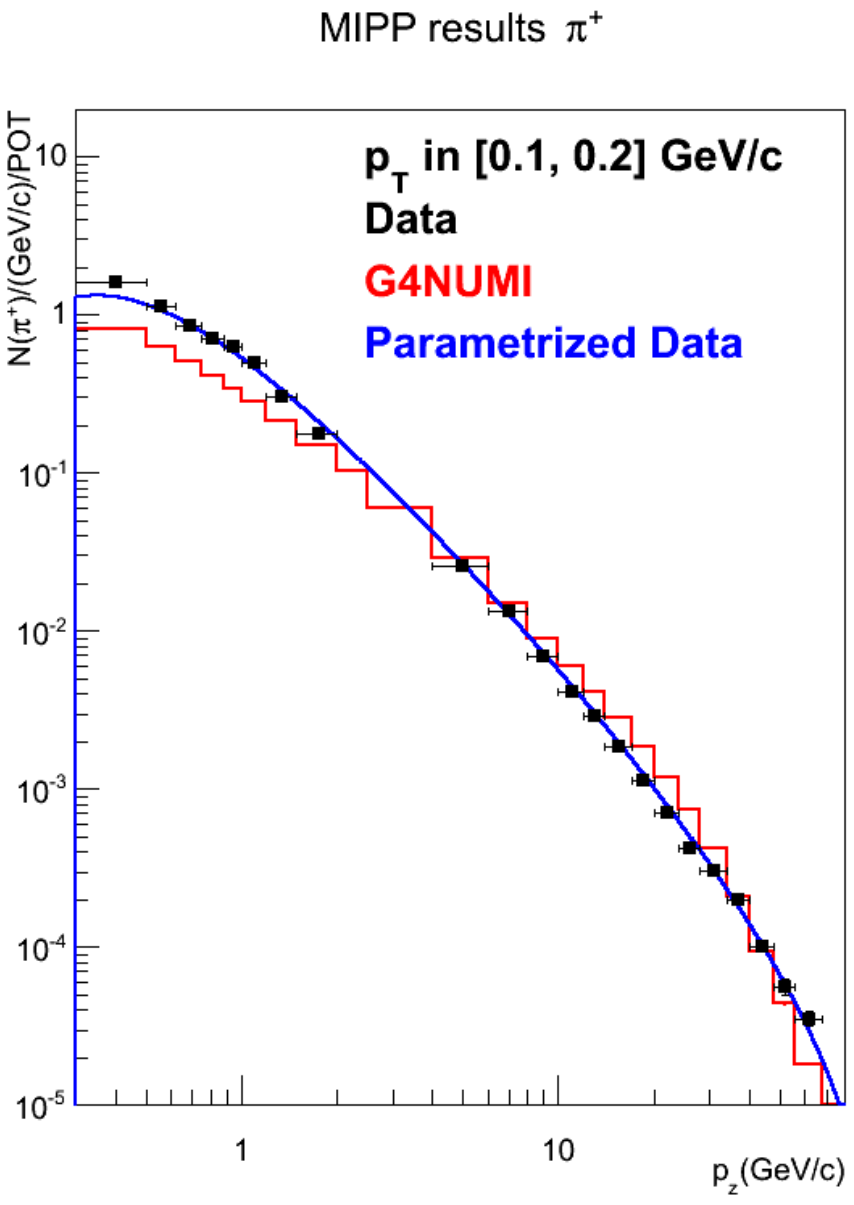
$$\frac{\Delta Y}{\Delta p_Z}$$

- **Data includes the error.**
- **Blue: parametrized yield (dY/dp_z).**
- **Red: g4numi prediction (FTFP_BERT).**
- Just π^+. (π^- in the backup slides).

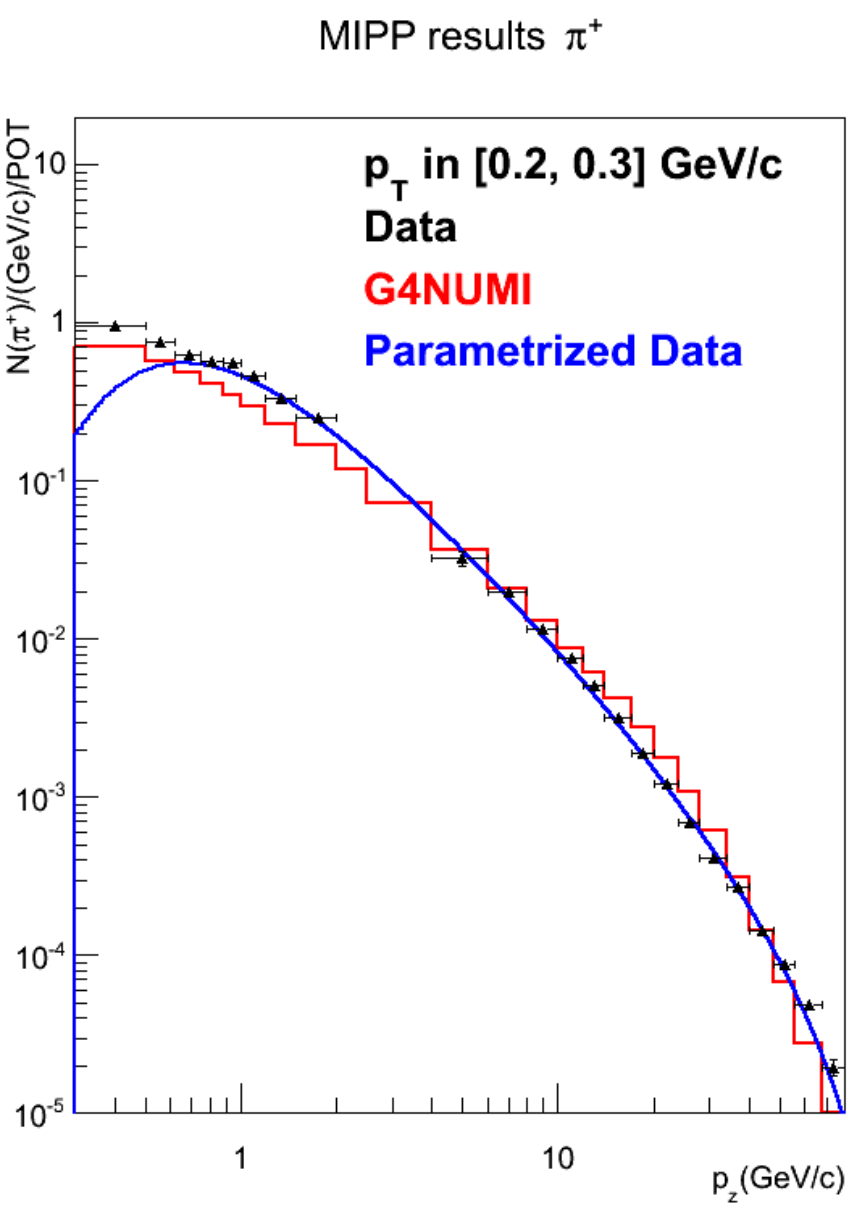


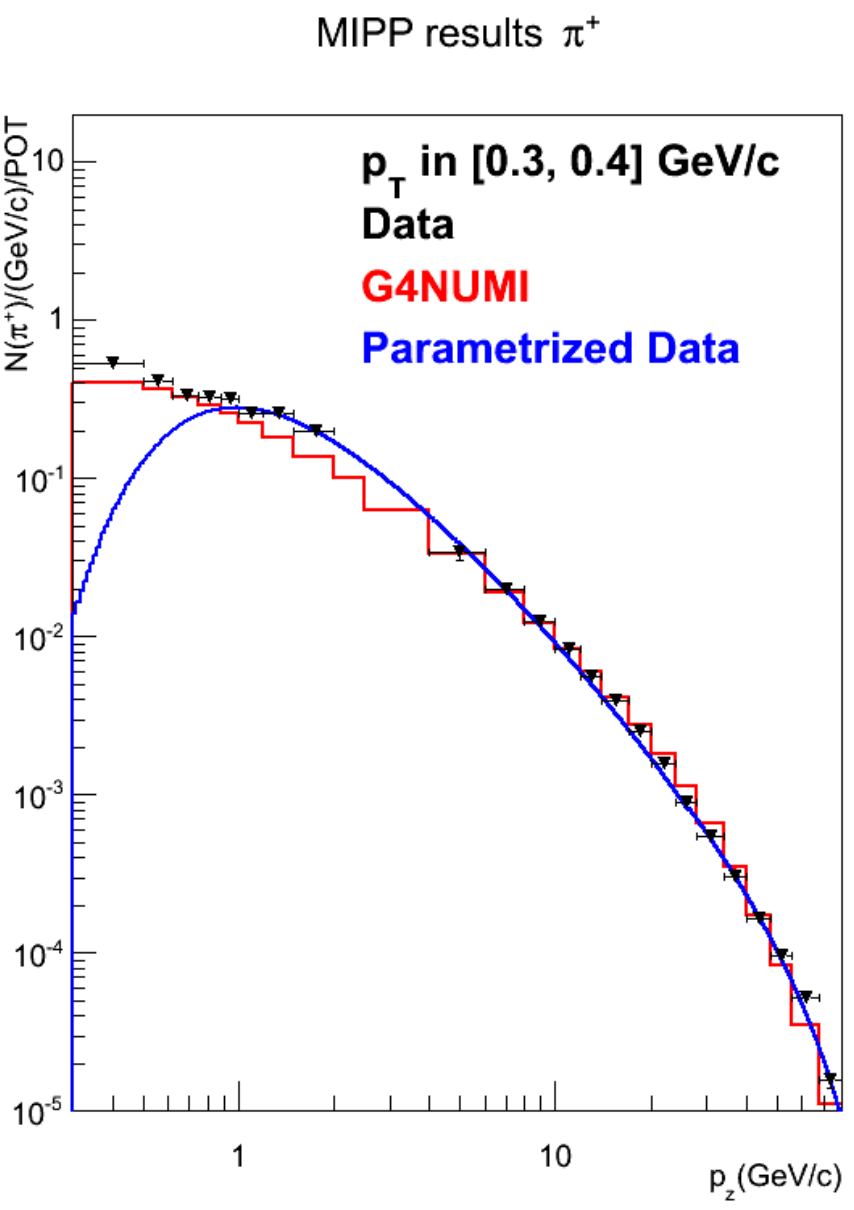
MIPP Data – Parametrization – g4numi comparison



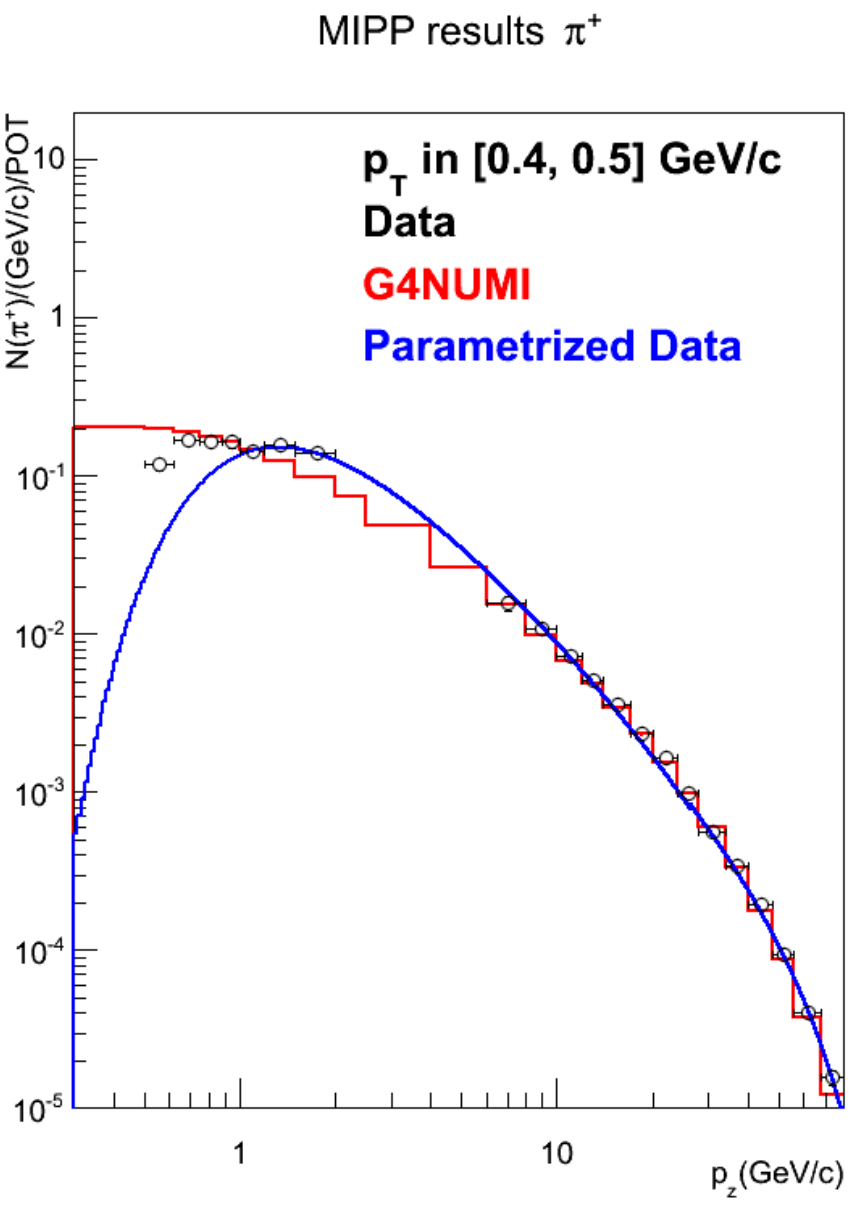


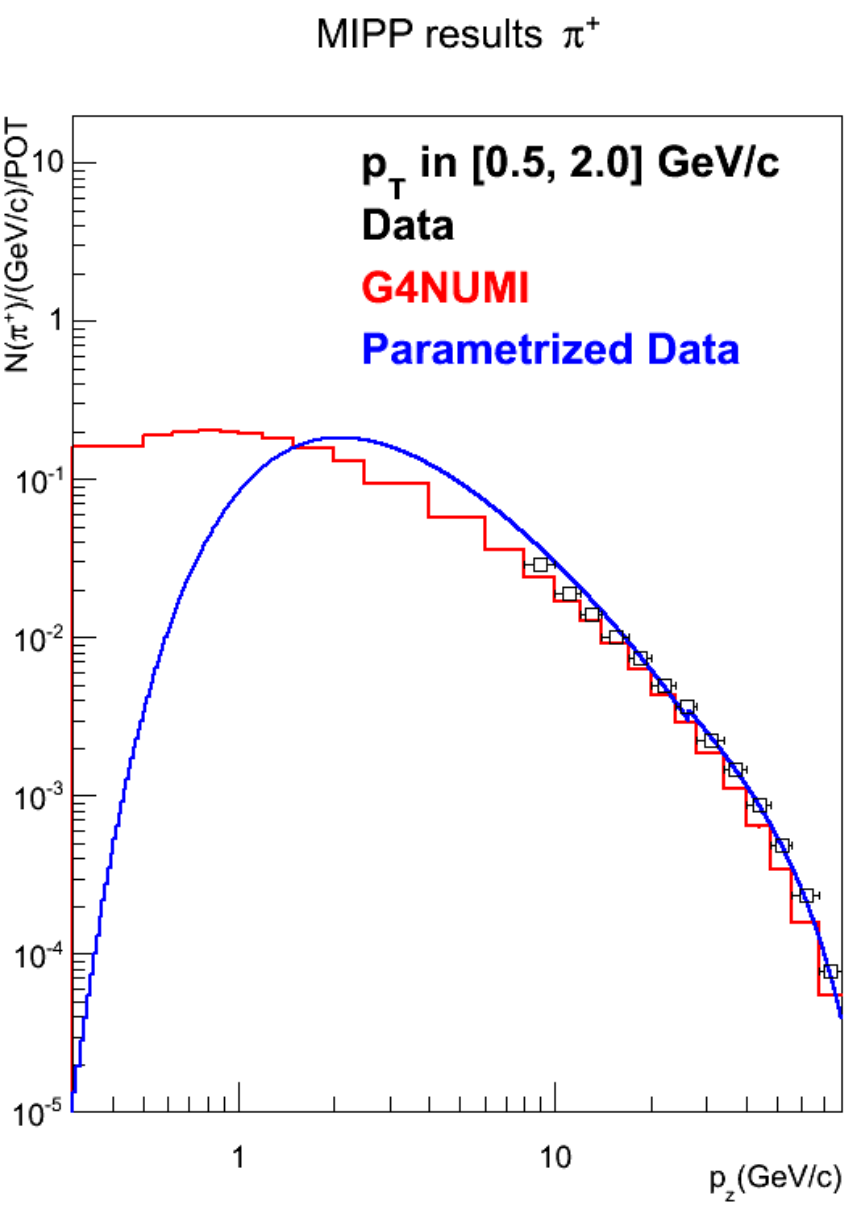
MIPP Data – Parametrization – g4numi comparison





MIPP Data – Parametrization – g4numi comparison

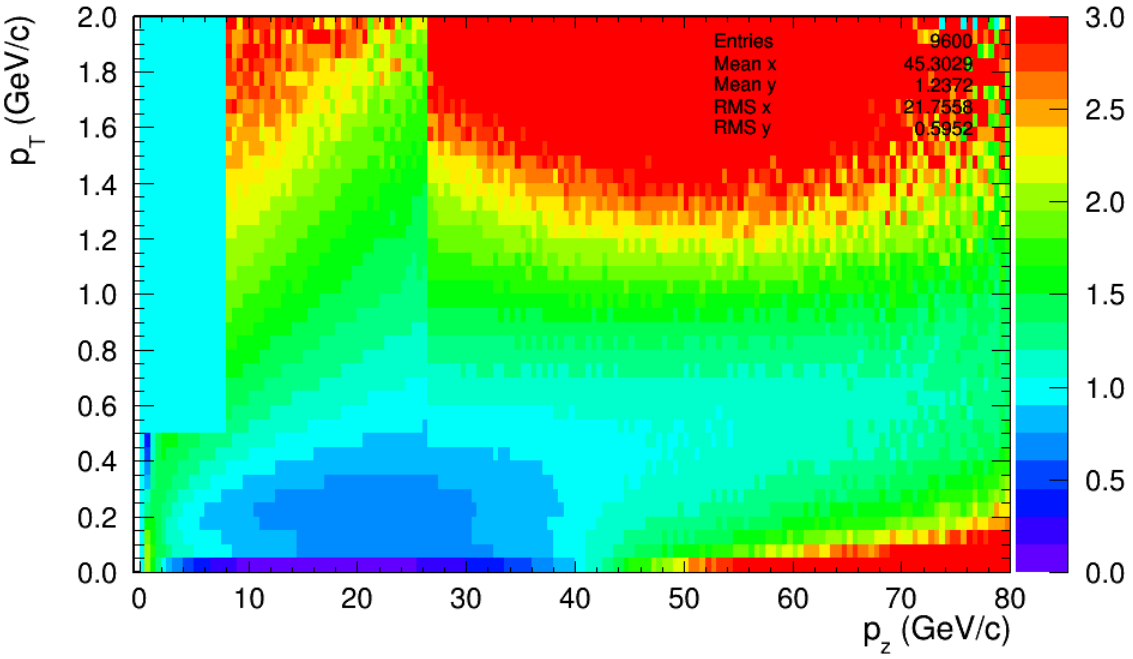




Weights applied for π^+

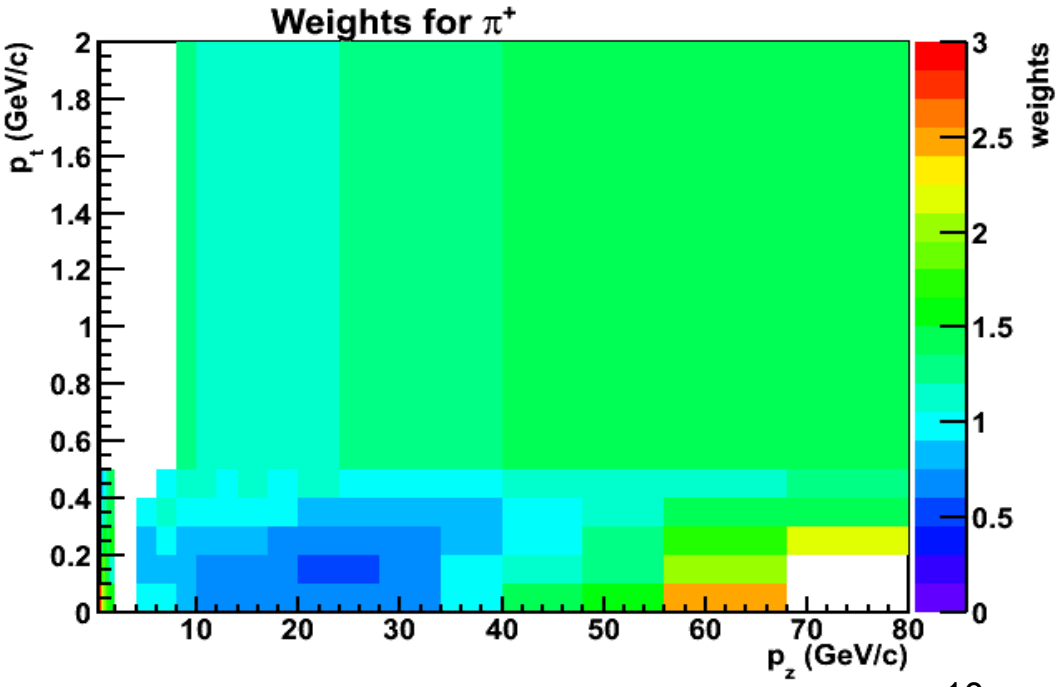
From Parametrization

$$weight = \frac{Parametrized\ yield}{g4numi\ yield}$$



From Data

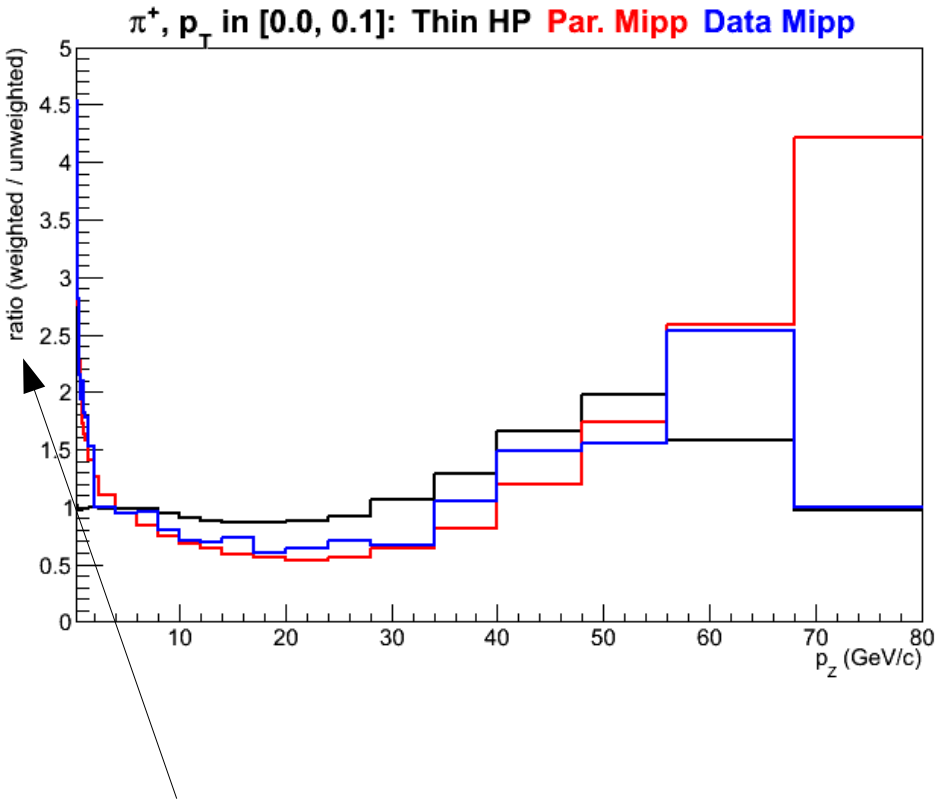
$$weight = \frac{Data\ yield}{g4numi\ yield}$$

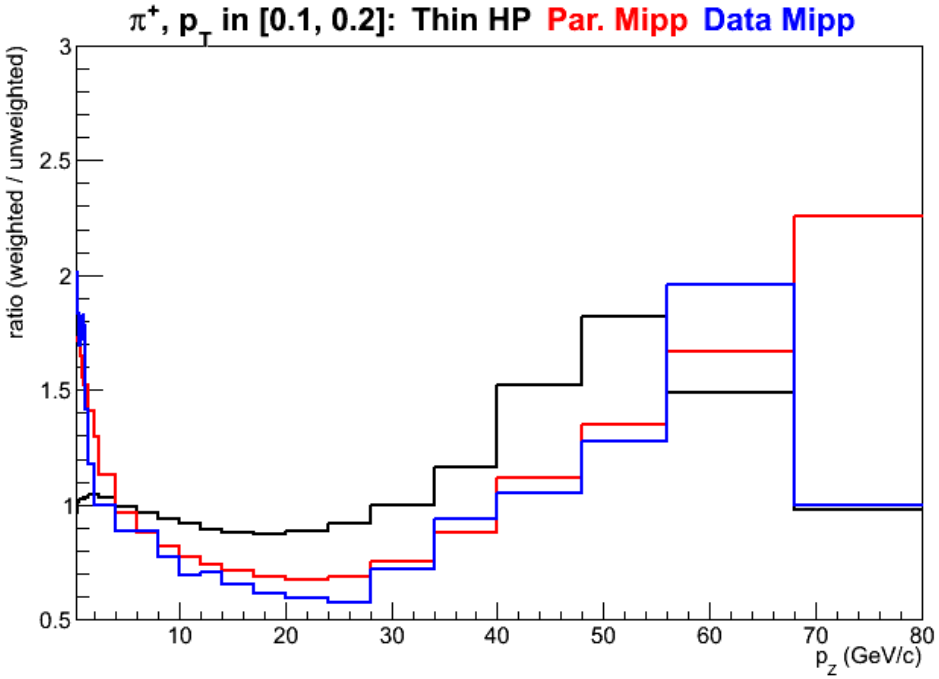


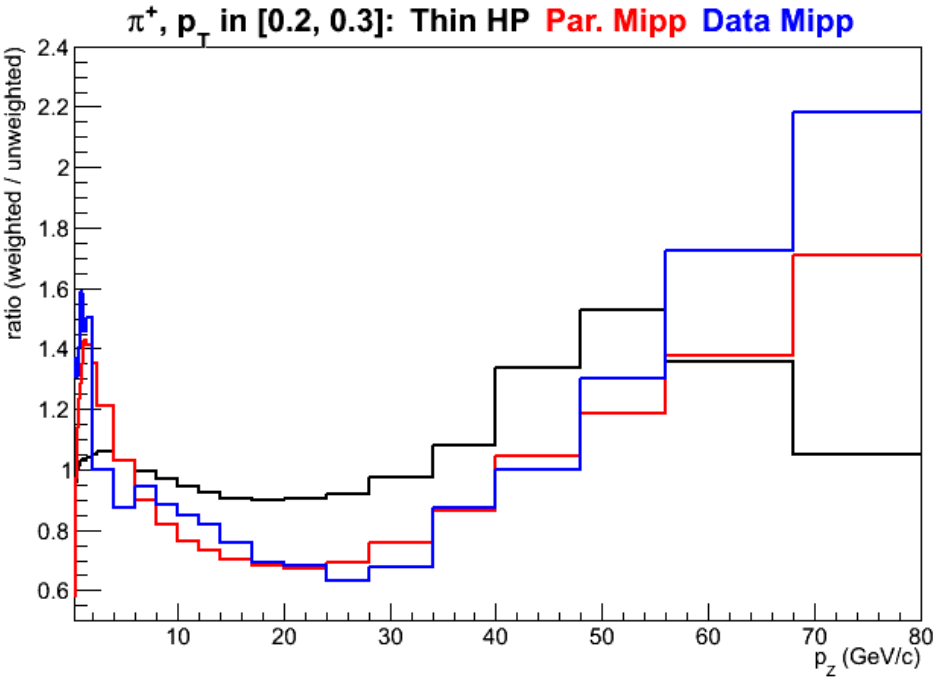
Bin by bin, no interpolation yet

Comparison of FTFP vs MIPP Replica vs Thin Target Corrected Yields

Comparison of π^+ yields off the target

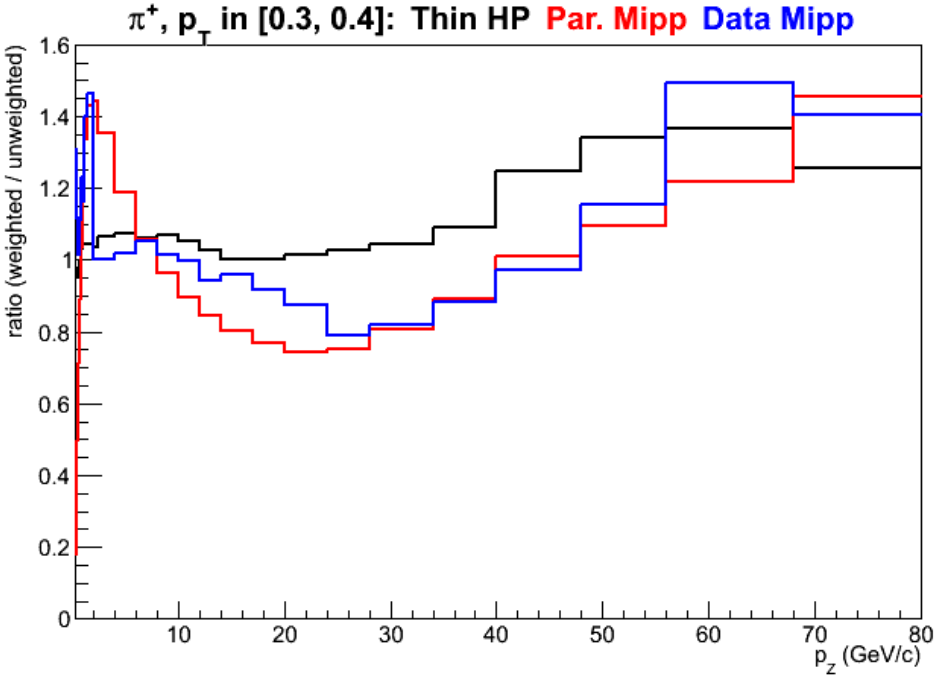


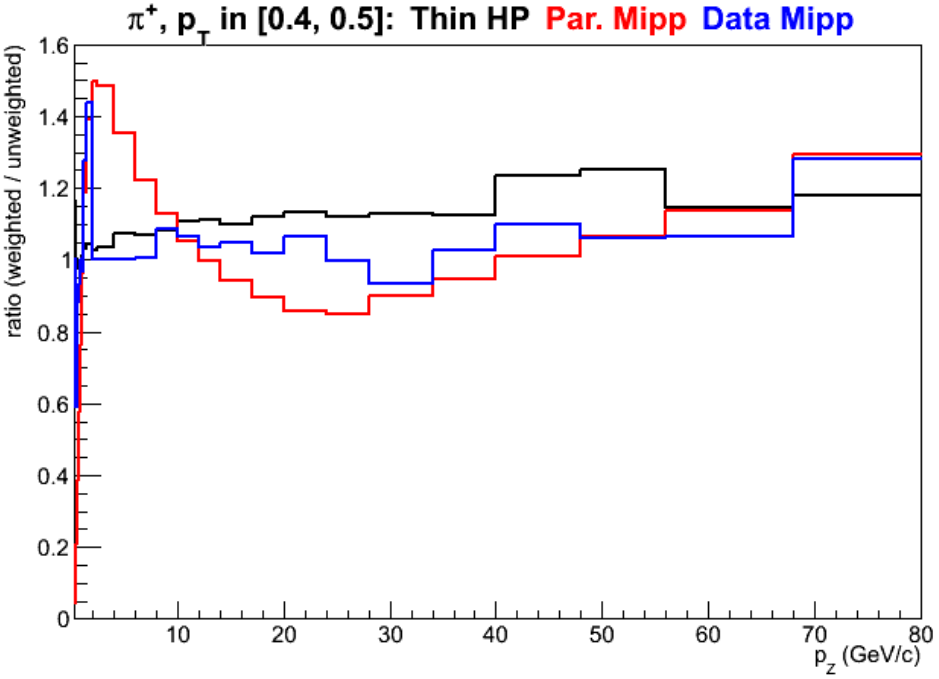


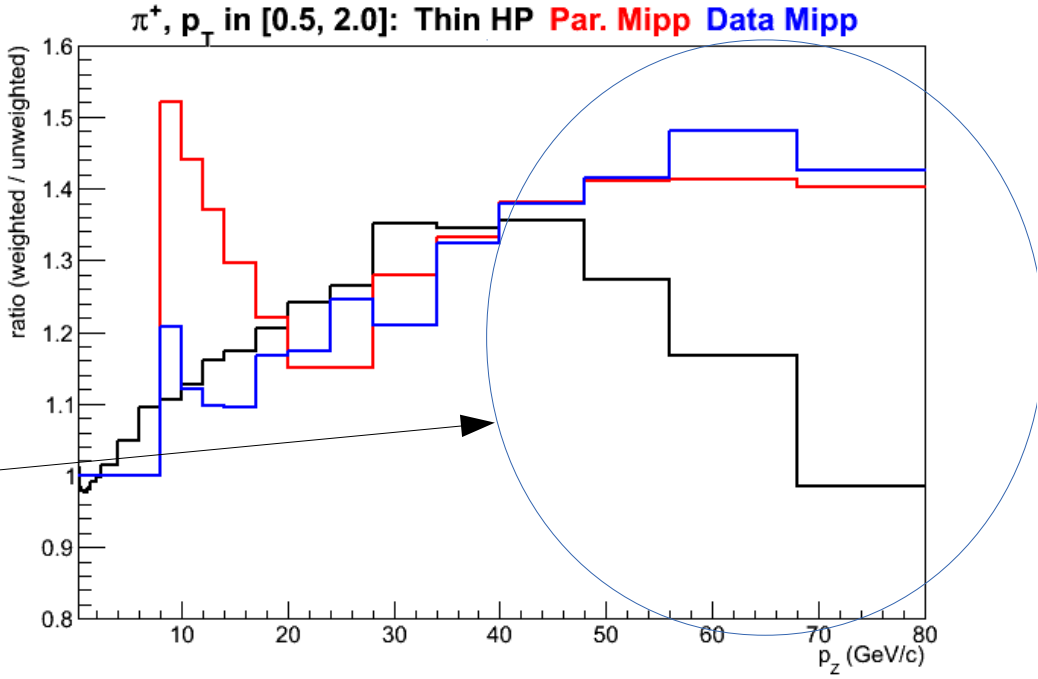


- Ratio over the FTFP prediction of pion production in the target.
- To use thin target data, we look into the ancestry of the hadron off the target in g4numi.

Comparison of π^+ yields off the target







- ***The discrepancy is obvious around the focusing peak.***

- We are applying few thin target correction for these pions.

Extending to High Energy Kaons

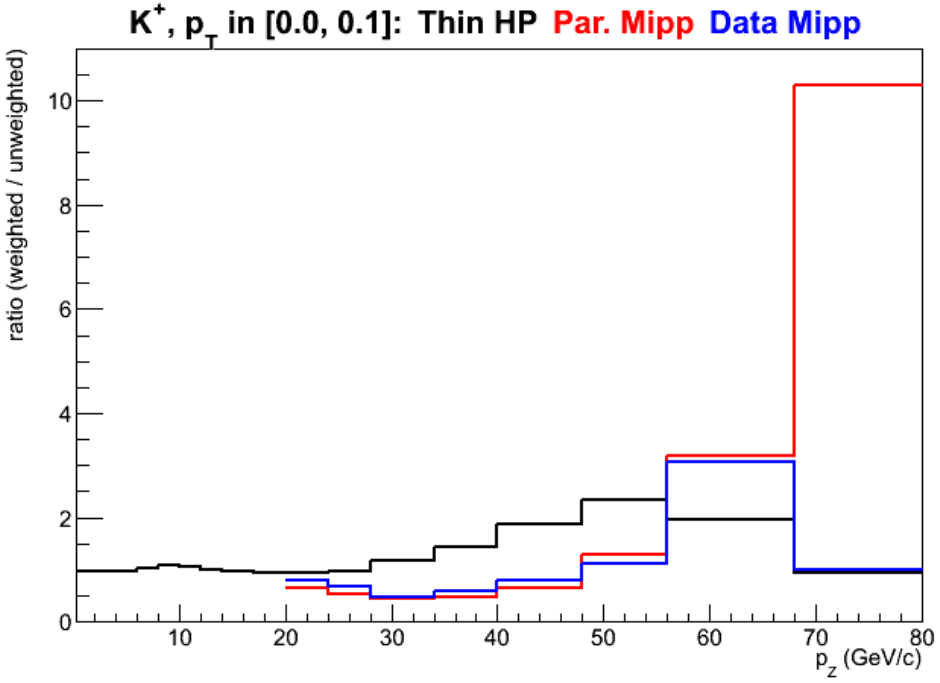
- MIPP data from Numi replica (Sharon's thesis):
  - ***Ratios: π^-/π^+, K^-/K^+, K^+/π^+ and K^-/π^- yields.***
  - ***Only for high momentum particle produced:***

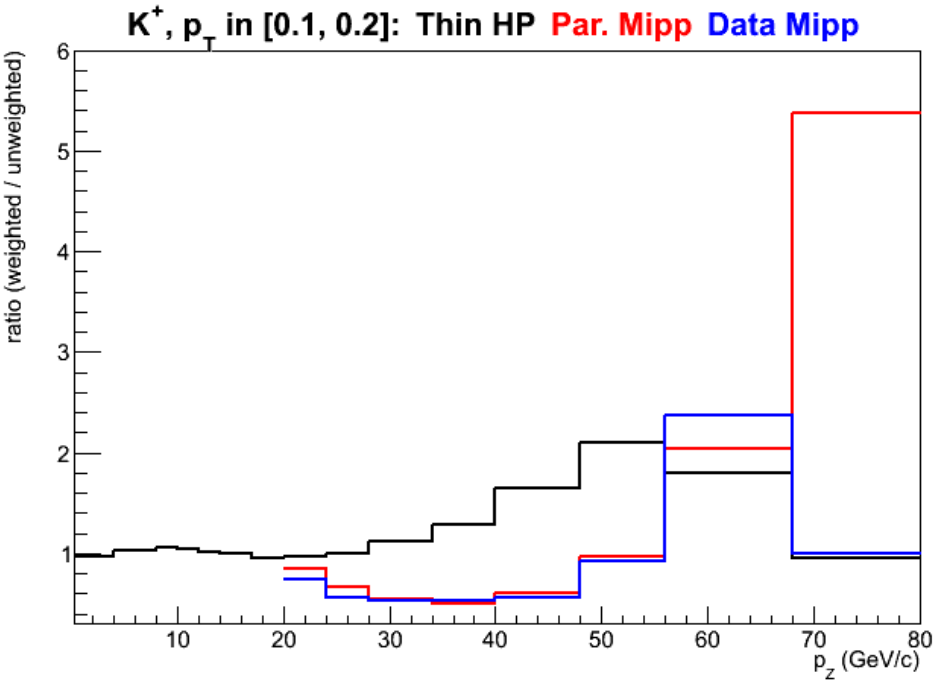
$$20 < p_z < 90\ GeV/c$$

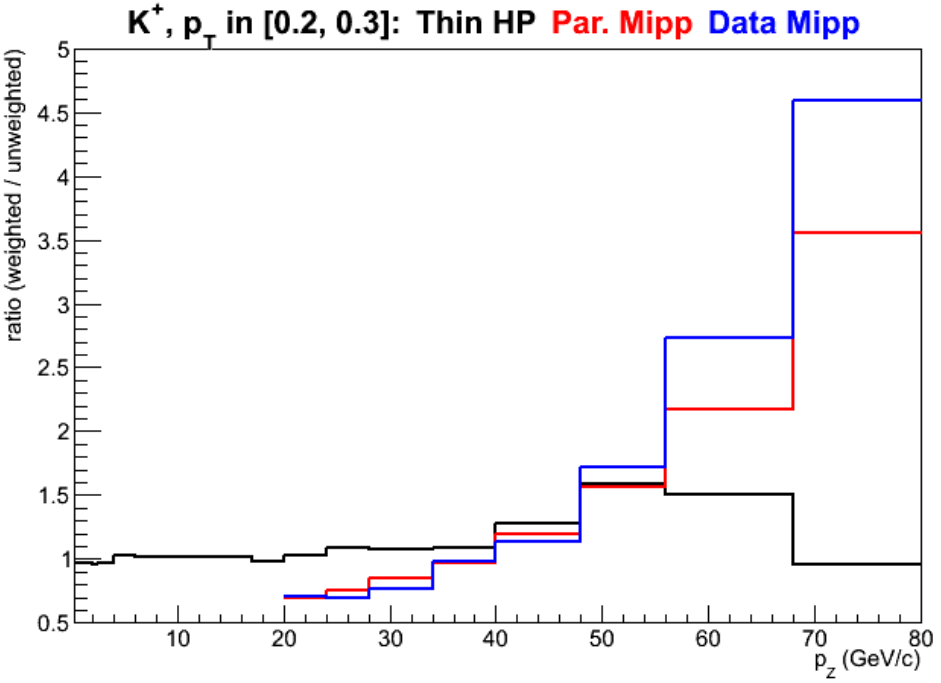
- We interpolate with a 2 degree polynomial (see backup).
- To get the weight:

$$weight(K) = \frac{yield(\pi) \times ratio(K/\pi)}{MC(K)}$$

Comparison of K^+ yields off the target

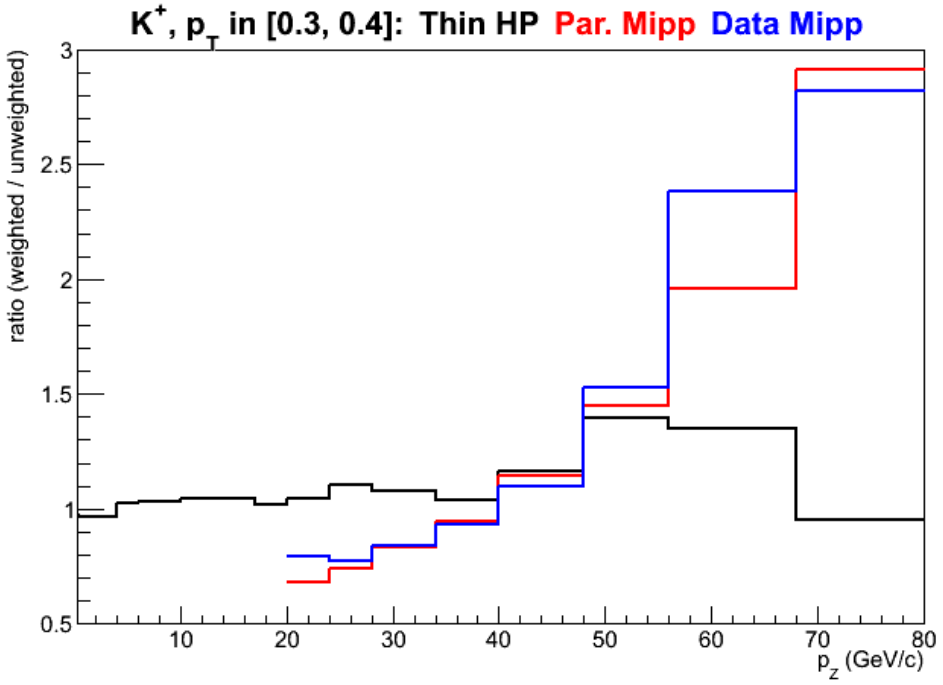


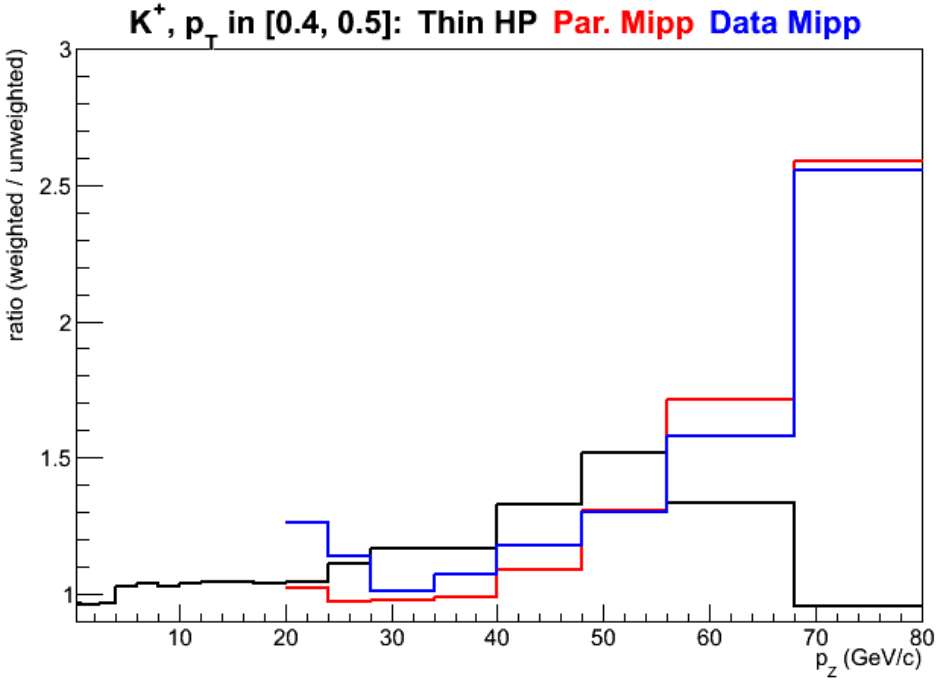


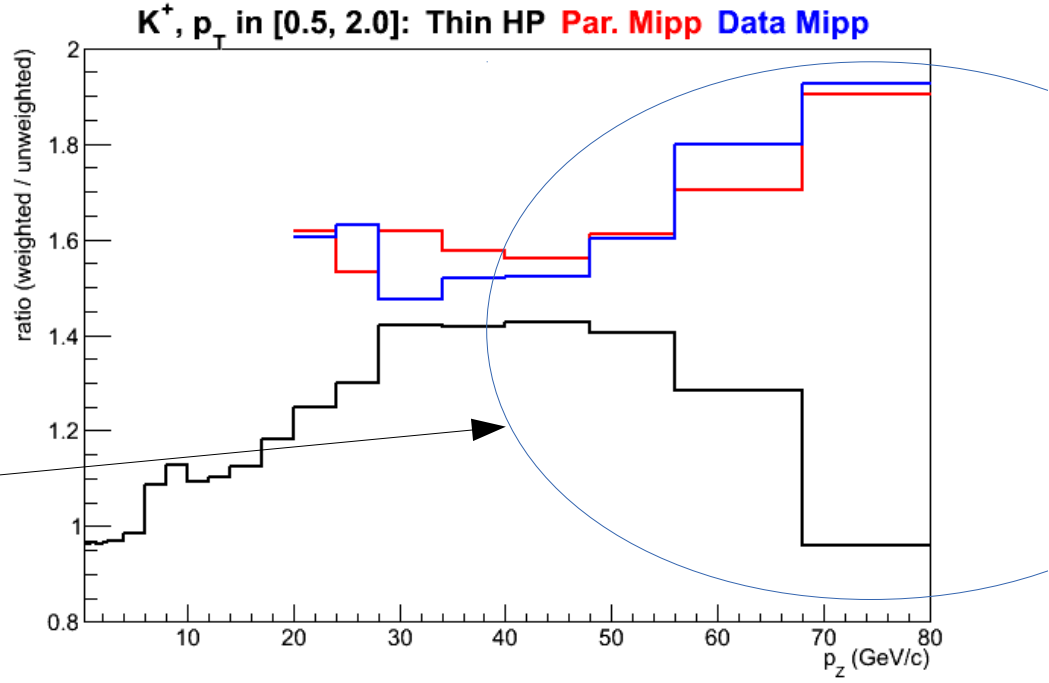


- Red and blue come from MIPP π^{+-} yield + Sharon's thesis.
- **Black low** energy comes from NA49 (Gemma's thesis) and **black high** energy from Lebedev + NA49 π.

Comparison of K^+ yields off the target

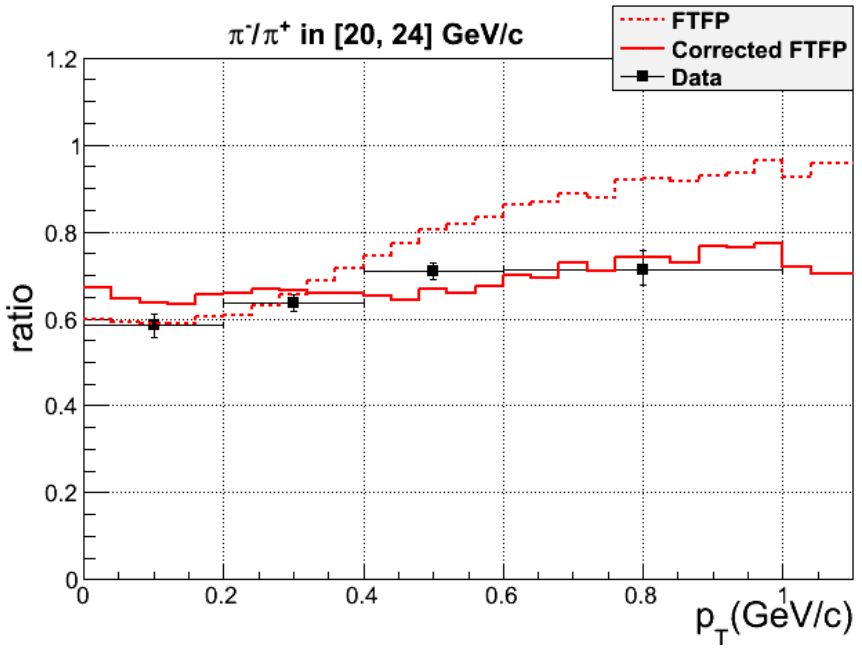


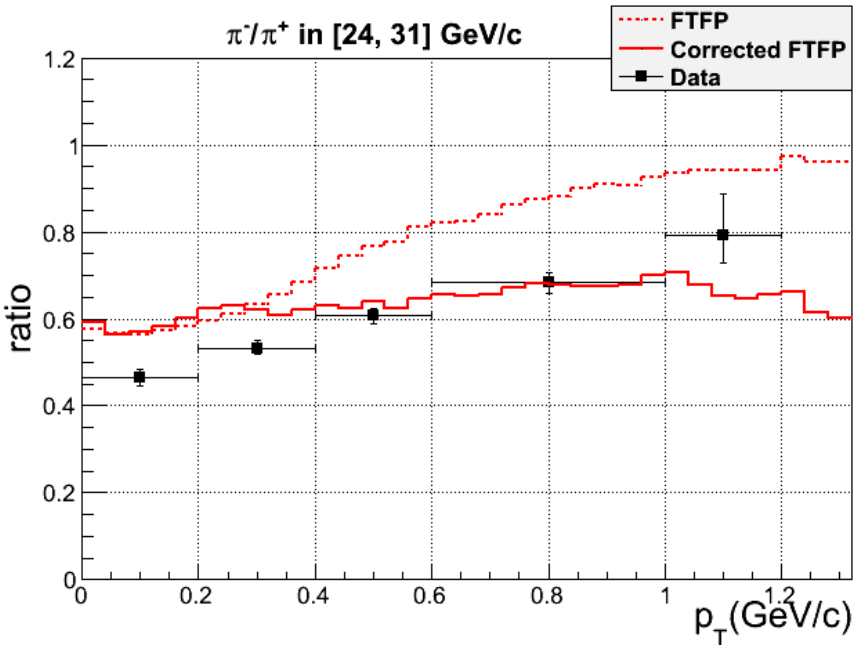




- We are applying few thin target correction for these kaons.

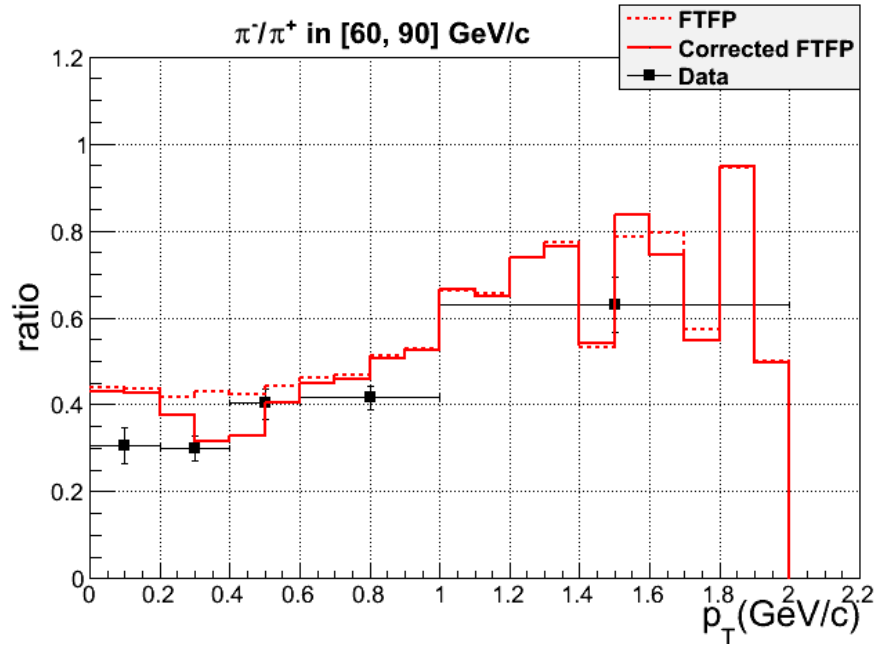
Check with Sharon's Ratios

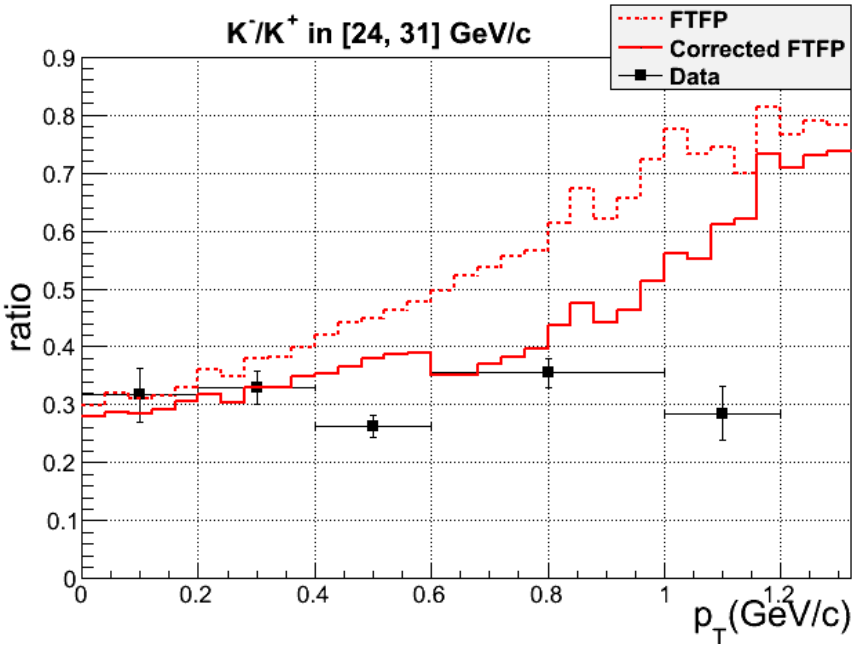




- **Corrected FTFP uses thin target data.**
- **Data is MIPP replica from Sharon's thesis.**

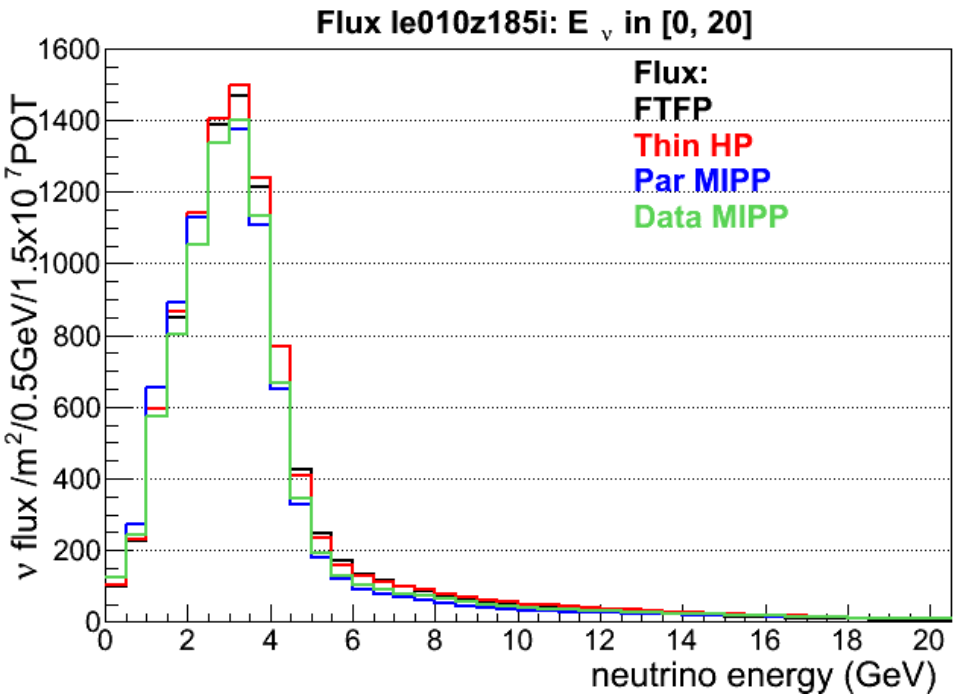
(more in backup slides)

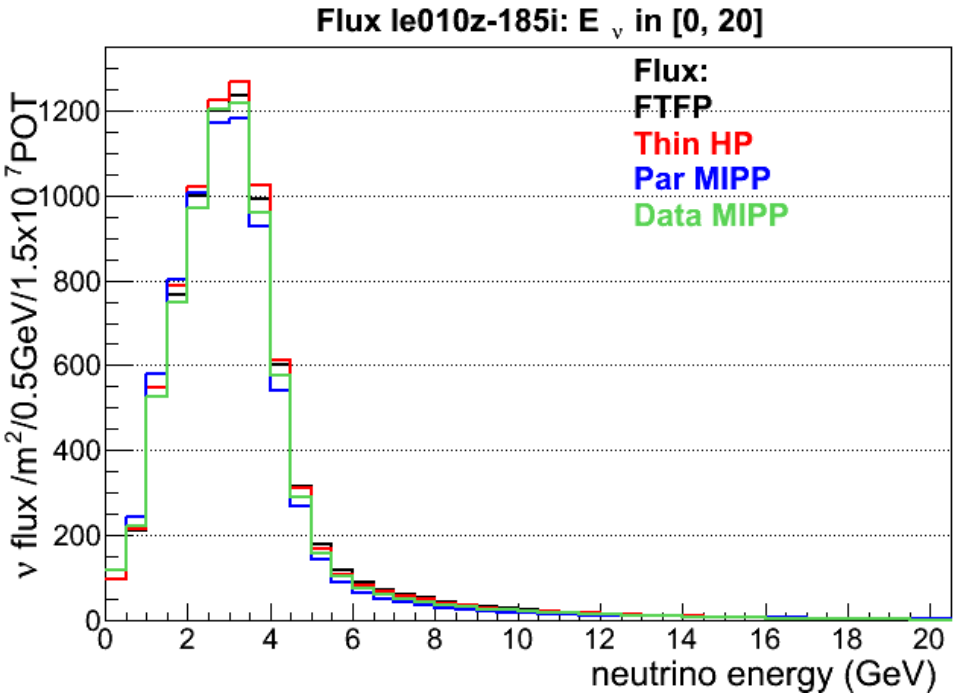




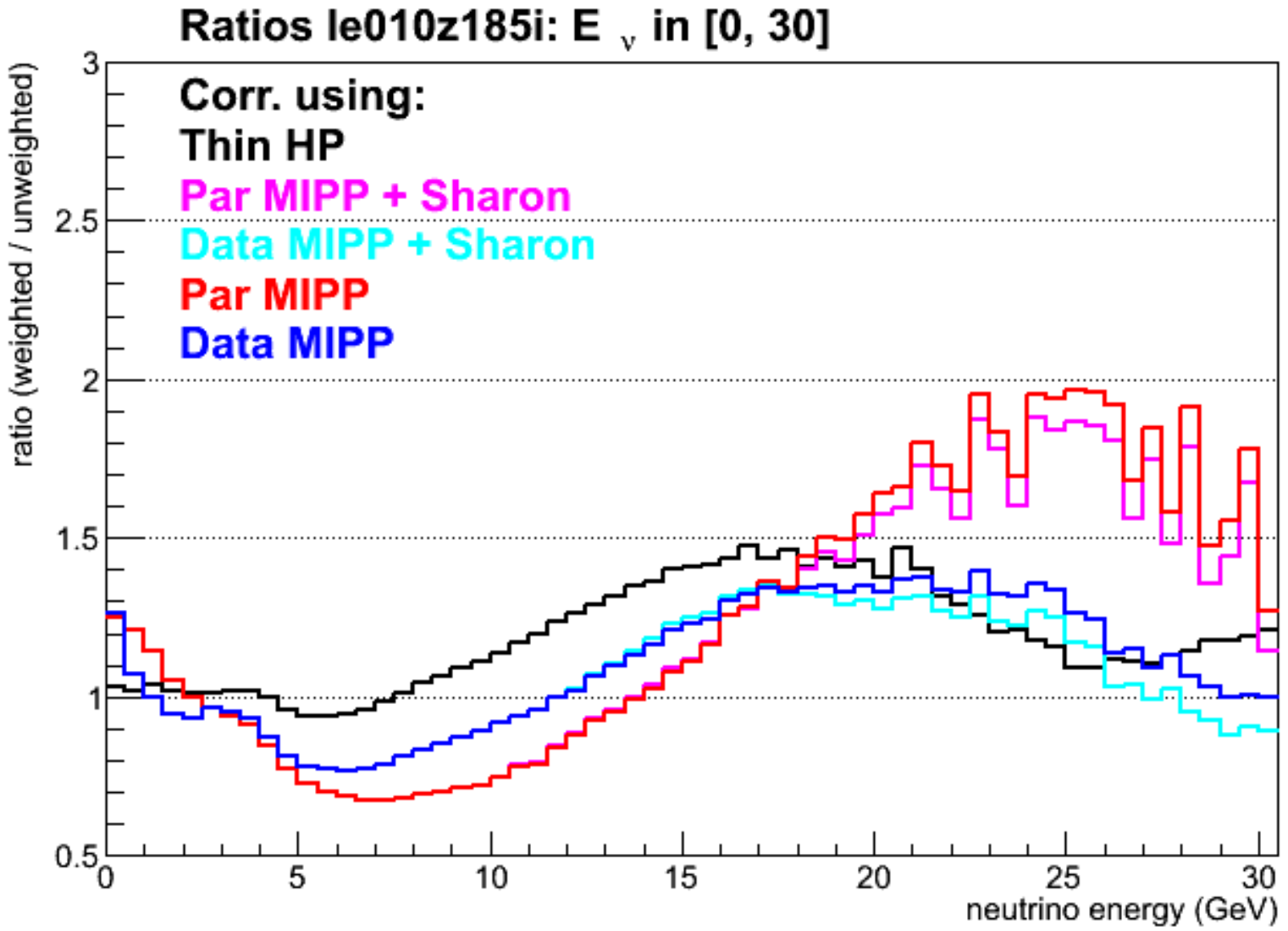
PRELIMINARY RESULTS

LE010z185i and LE010z-185i Fluxes

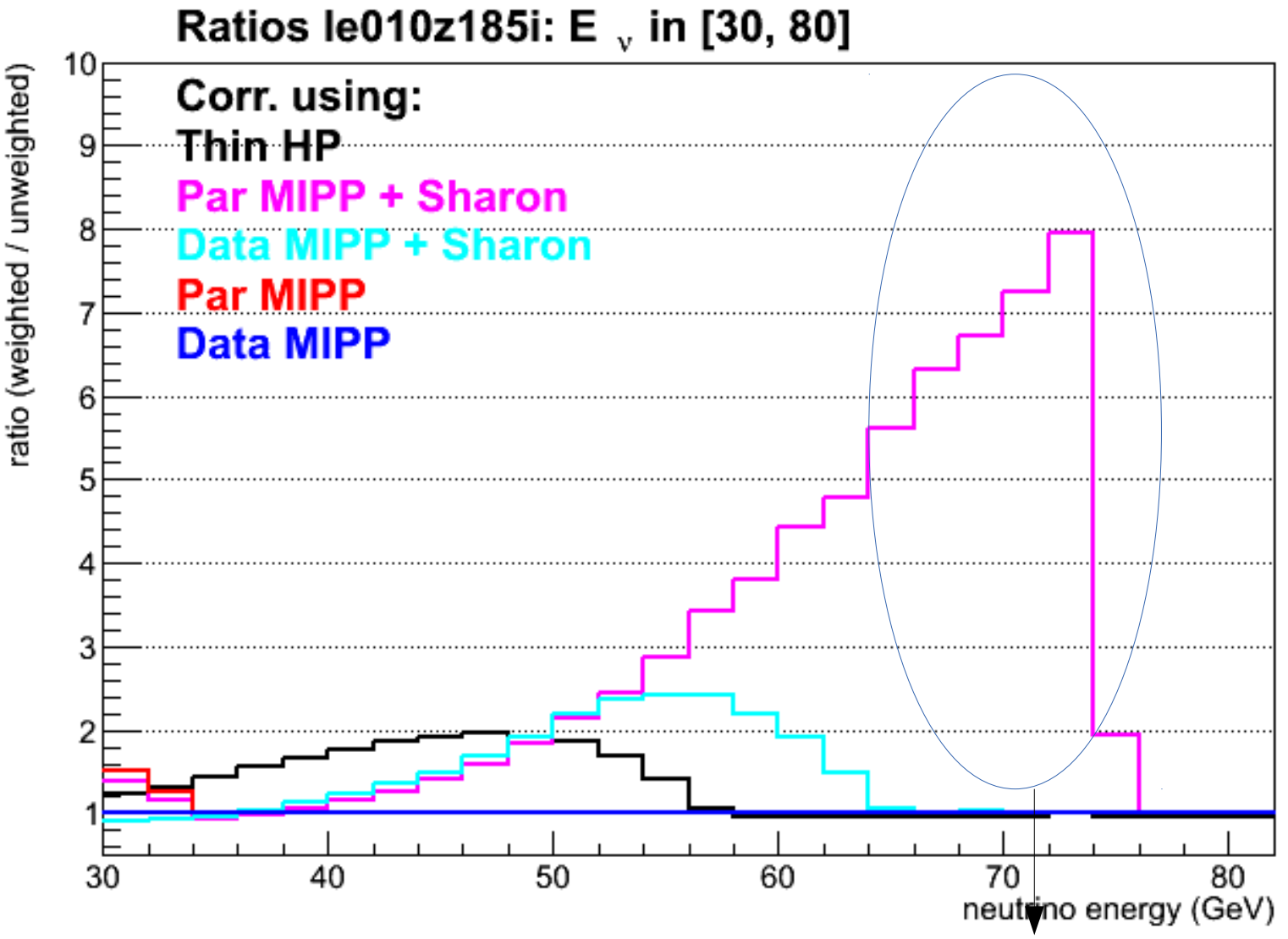




Corrected Flux Over FTFP Prediction
LE FHC



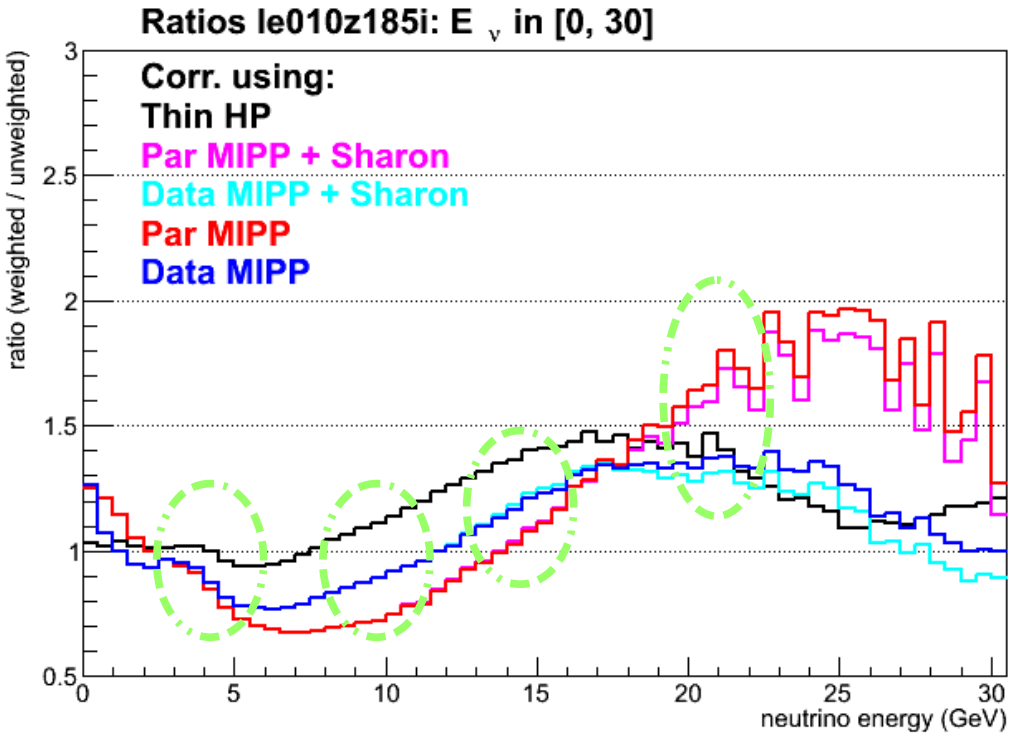
Corrected Flux Over FTFP Prediction
LE FHC



needs additional investigation!

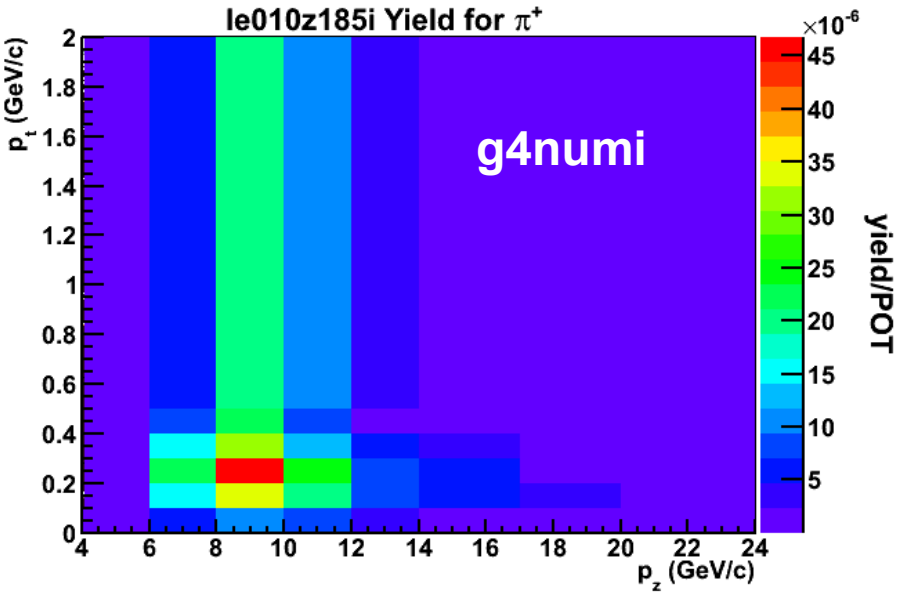
Looking into MIPP's Impact on the Flux

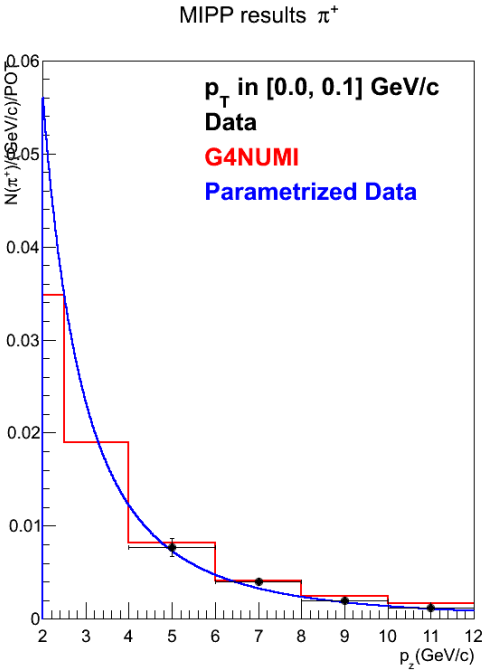
We look closely at four neutrino energy regions:

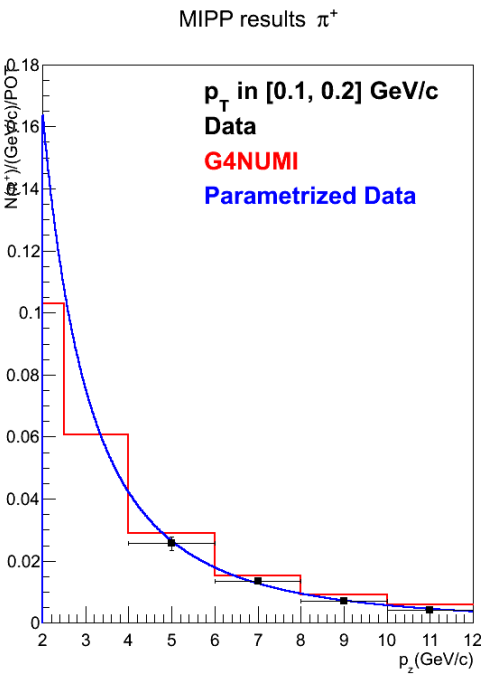


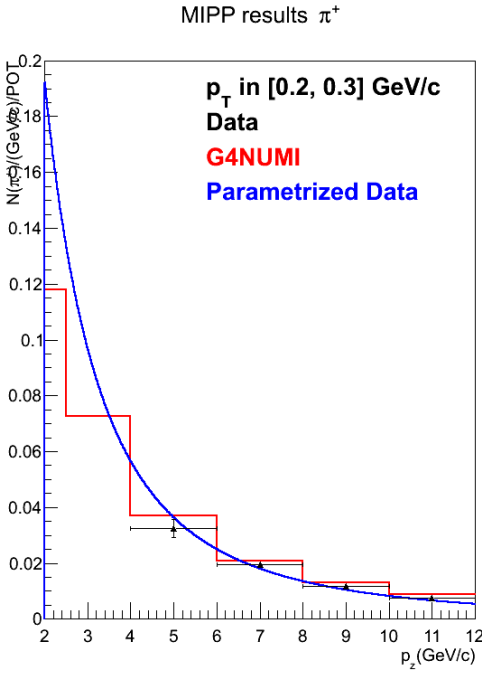
[3, 5] GeV/c [9, 11] GeV/c [13, 15] GeV/c [20, 22] GeV/c

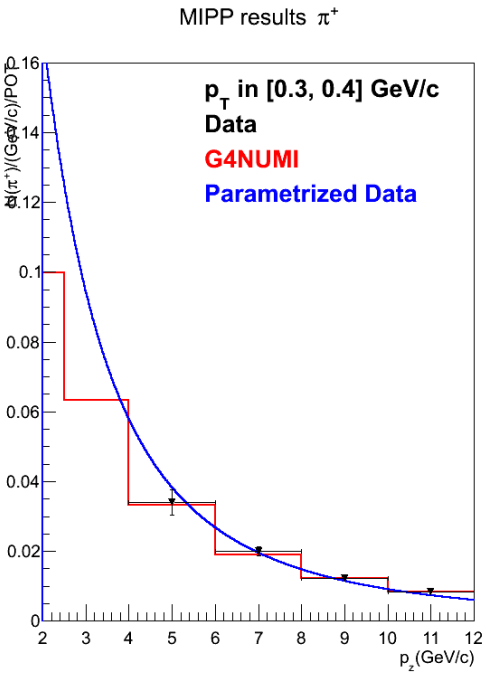
E_ν in [3, 5] GeV/c

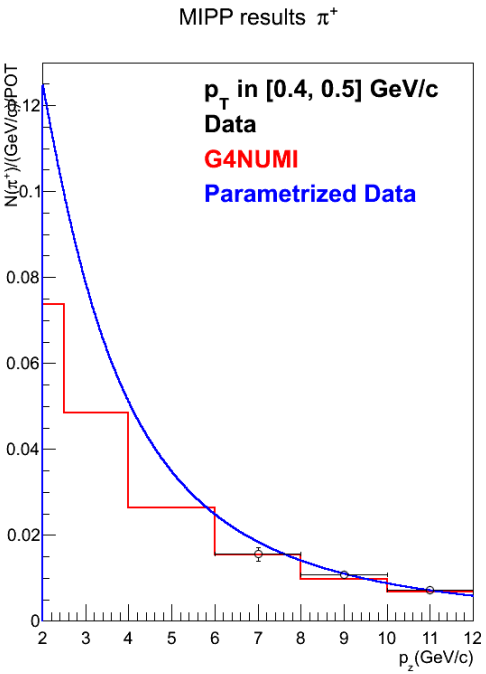


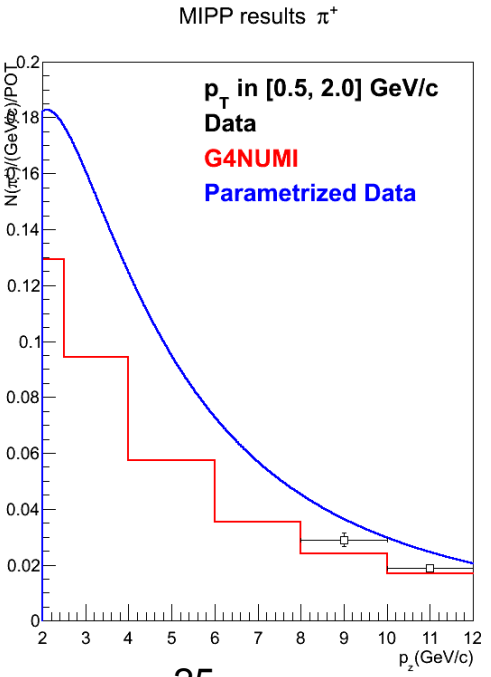




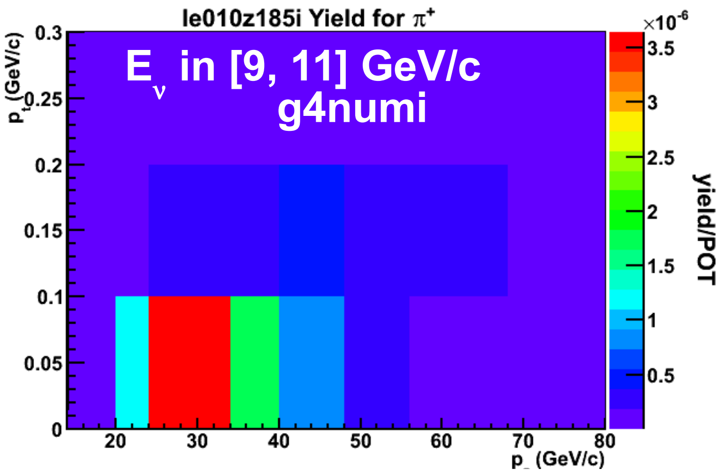


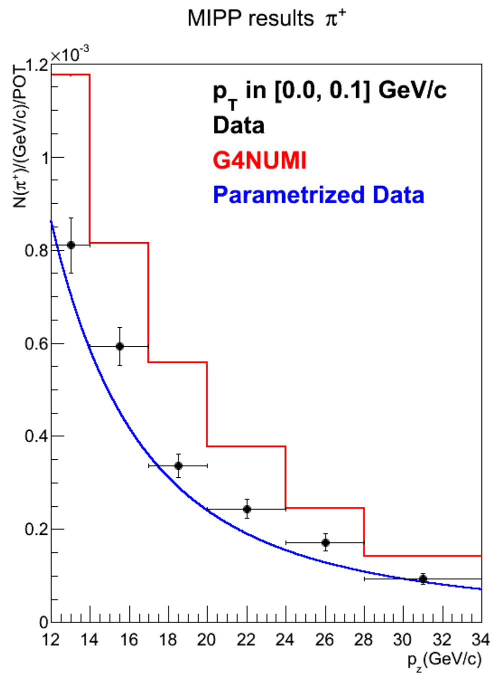


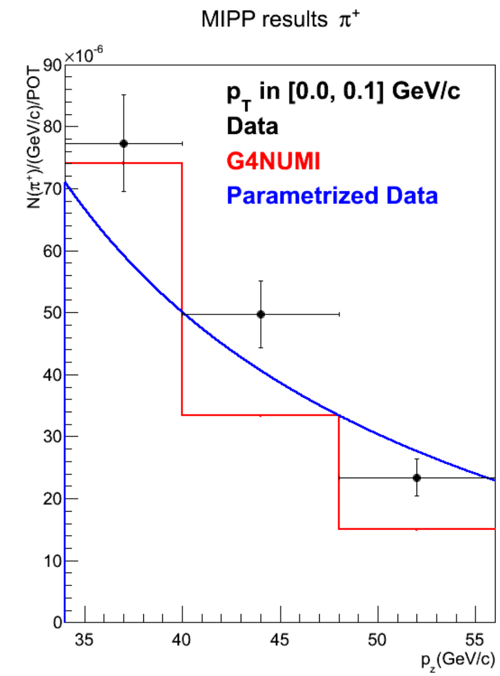


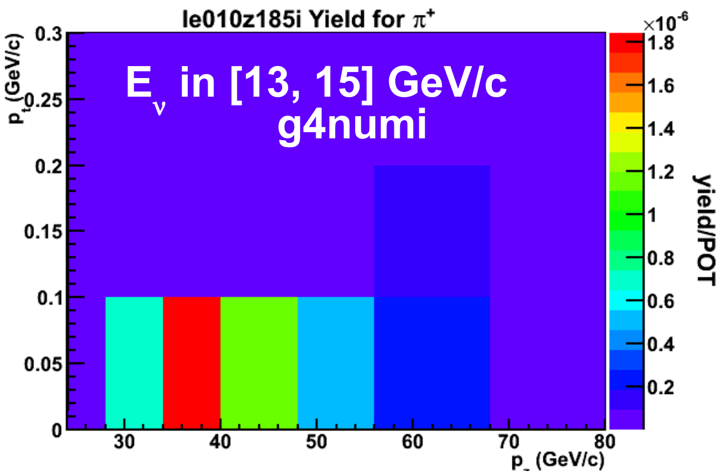


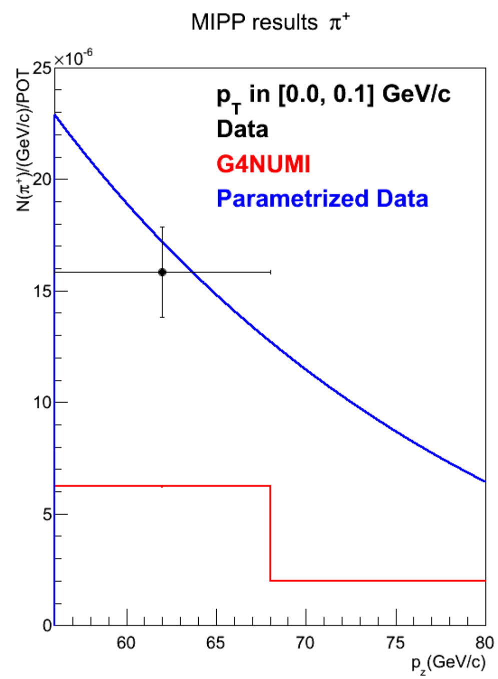
Higher Energies

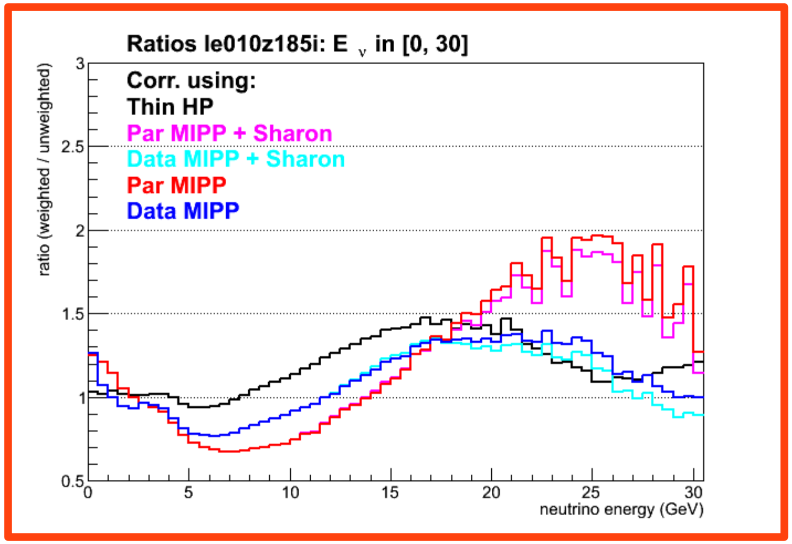


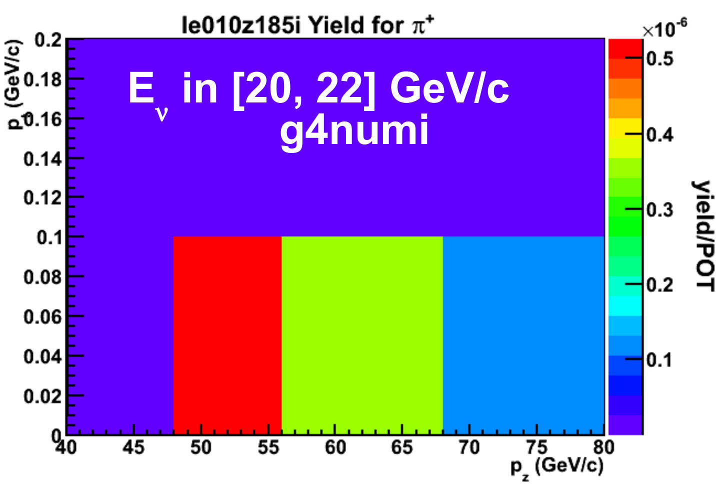












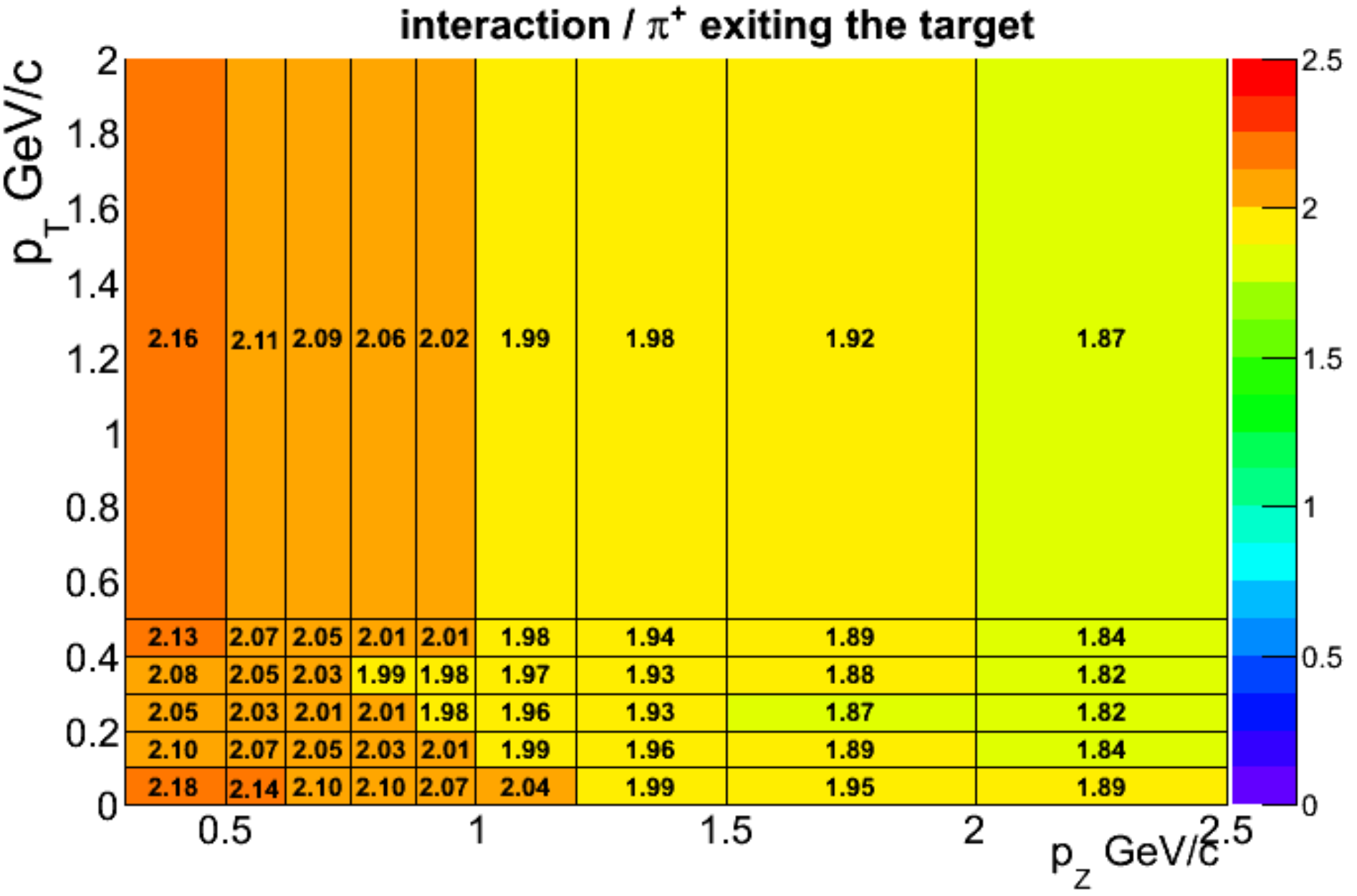
Why are NA49 and MIPP so different, specially in low energy neutrinos?

Hypothesis:
Caused by pion reinteractions in the target

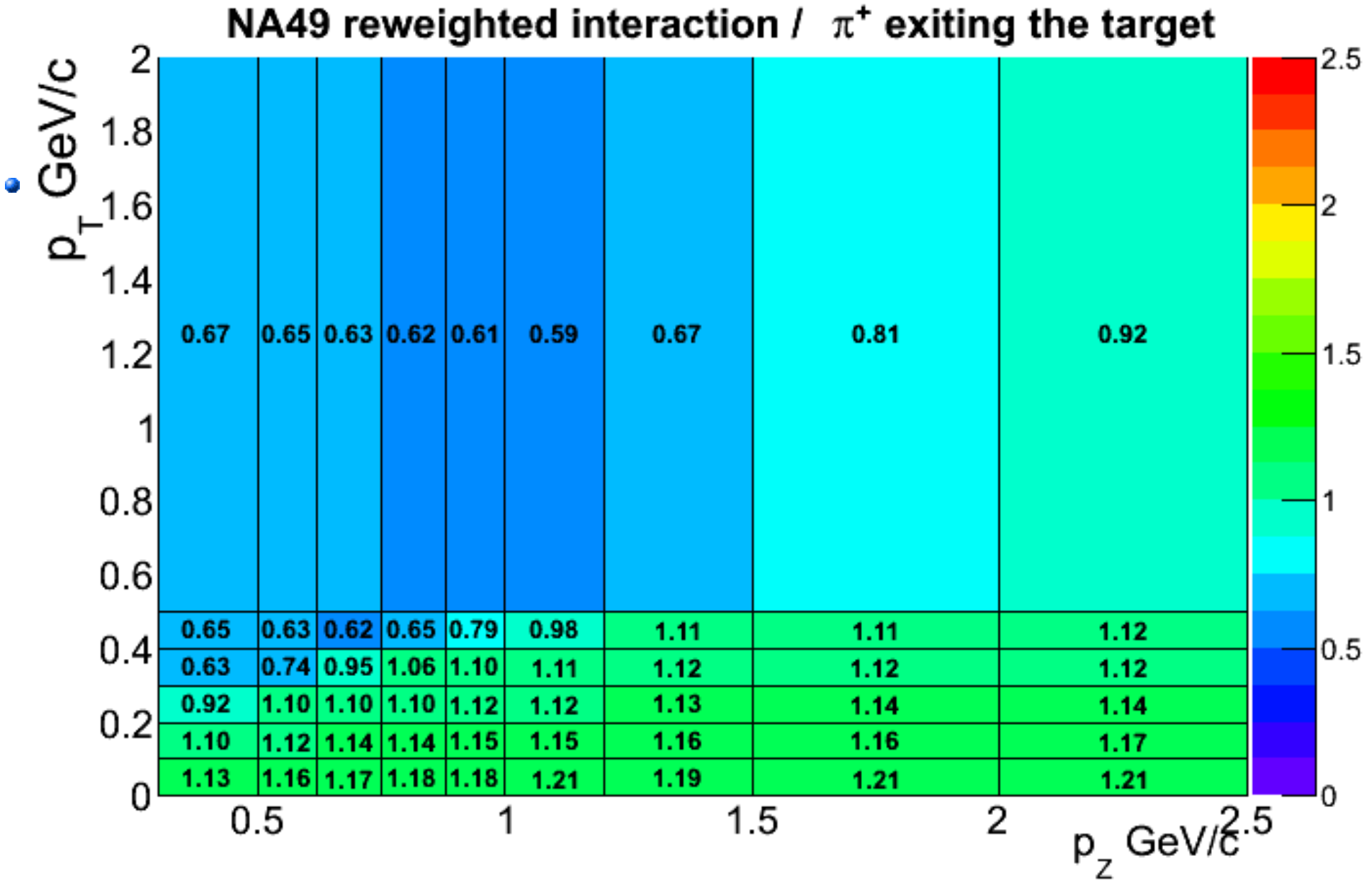
Let's take a look...

- *First: π^+ that exit the target.*
- *Second: π^+ in the neutrino history.*
- *Third: π^+ cross total section.*

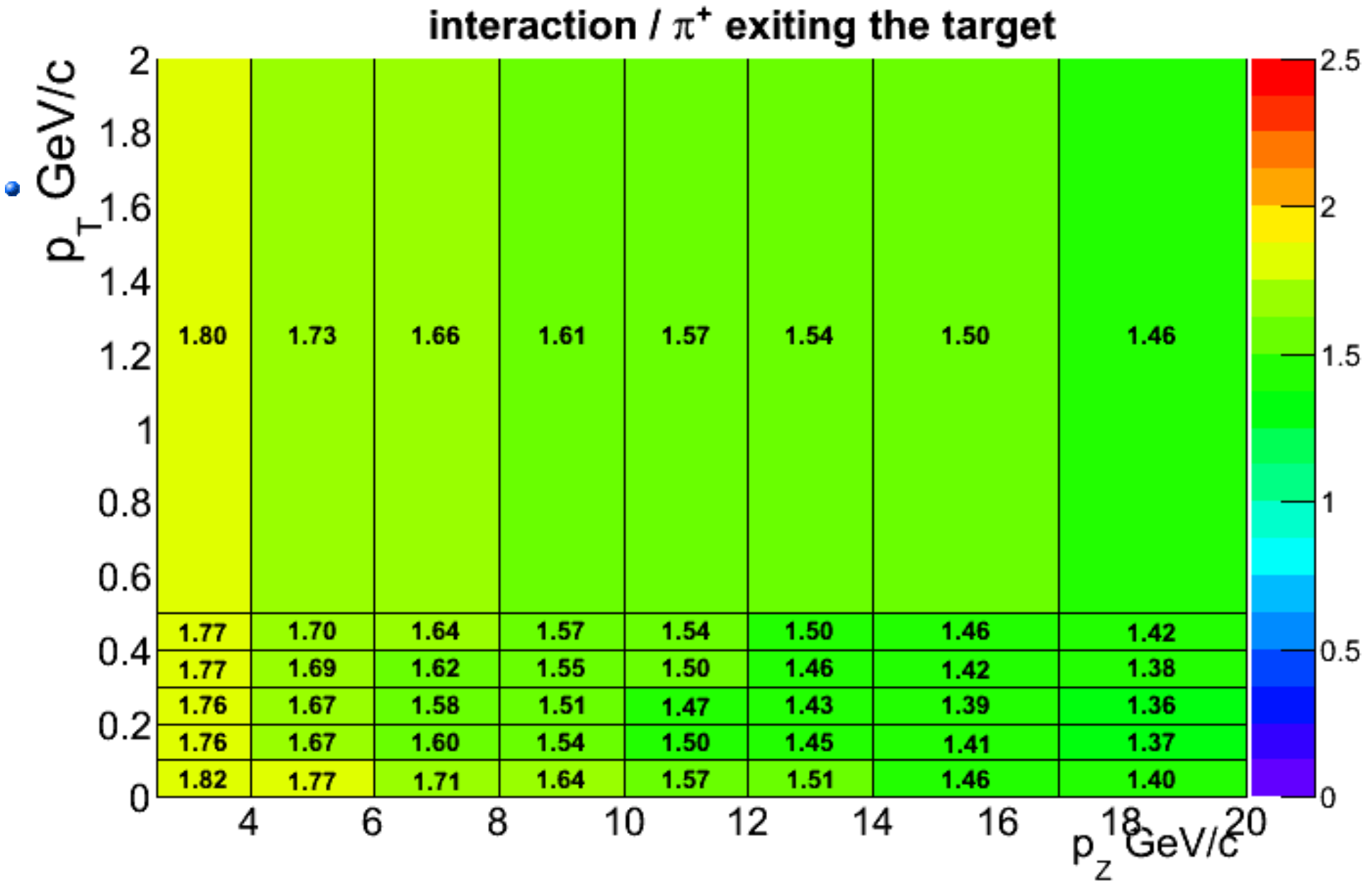
$0<p_z<2.5$ GeV/c


interaction / π+ exiting the target
pT GeV/c
pz GeV/c
2.16 2.11 2.09 2.06 2.02 1.99 1.98 1.92 1.87
2.13 2.07 2.05 2.01 2.01 1.98 1.94 1.89 1.84
2.08 2.05 2.03 1.99 1.98 1.97 1.93 1.88 1.82
2.05 2.03 2.01 2.01 1.98 1.96 1.93 1.87 1.82
2.10 2.07 2.05 2.03 2.01 1.99 1.96 1.89 1.84
2.18 2.14 2.10 2.10 2.07 2.04 1.99 1.95 1.89

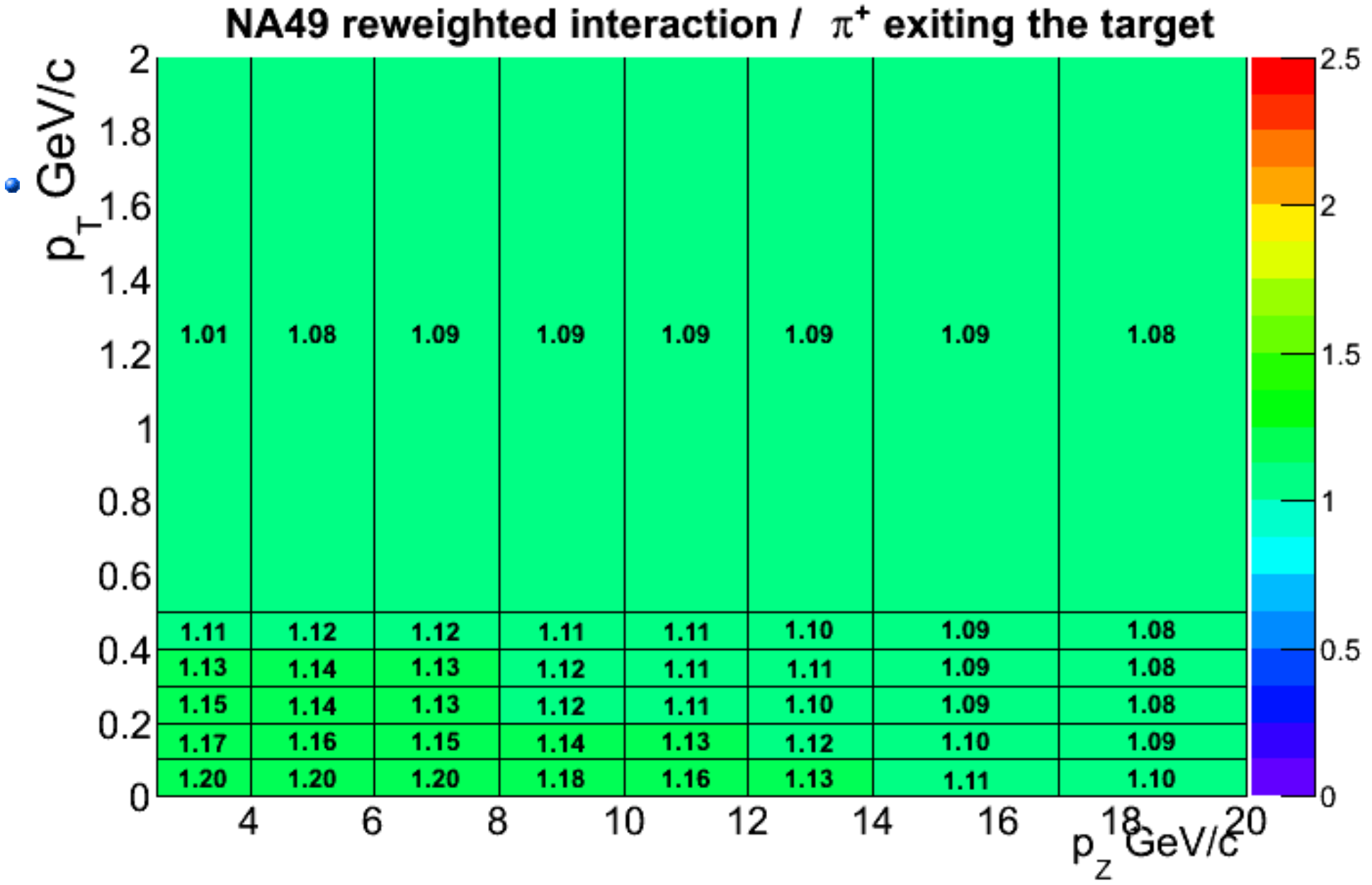
$0<p_z<2.5$ GeV/c


NA49 reweighted interaction / π^+ exiting the target
p_T GeV/c
p_z GeV/c
0.67 0.65 0.63 0.62 0.61 0.59 0.67 0.81 0.92
0.65 0.63 0.62 0.65 0.79 0.98 1.11 1.11 1.12
0.63 0.74 0.95 1.06 1.10 1.11 1.12 1.12 1.12
0.92 1.10 1.10 1.10 1.12 1.12 1.13 1.14 1.14
1.10 1.12 1.14 1.14 1.15 1.15 1.16 1.16 1.17
1.13 1.16 1.17 1.18 1.18 1.21 1.19 1.21 1.21

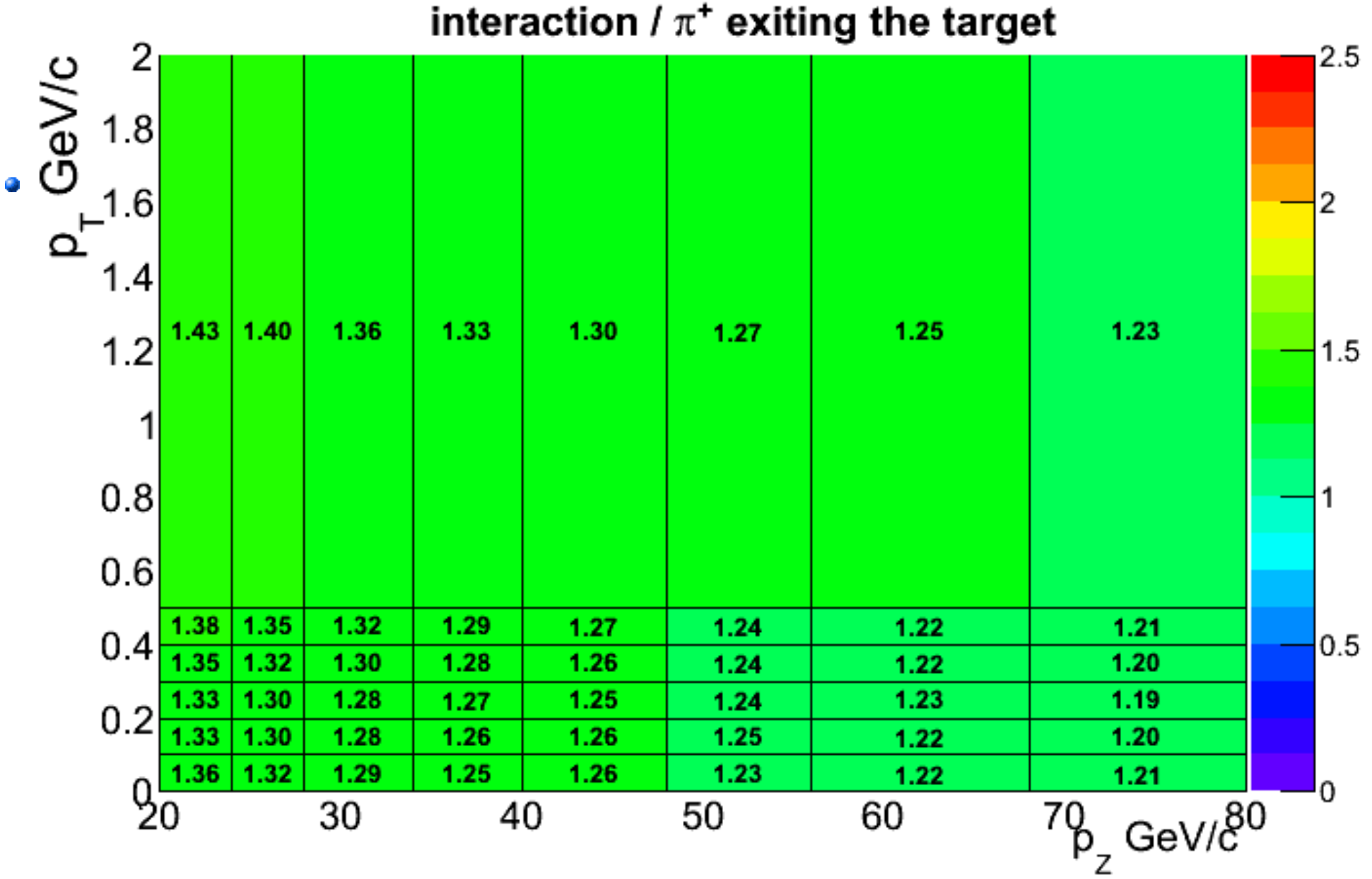
$4<p_z<20$ GeV/c


interaction / π+ exiting the target
pT GeV/c
pz GeV/c
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4
6
8
10
12
14
16
18
20
2.5
2
1.5
1
0.5
0
1.80 1.73 1.66 1.61 1.57 1.54 1.50 1.46
1.77 1.70 1.64 1.57 1.54 1.50 1.46 1.42
1.77 1.69 1.62 1.55 1.50 1.46 1.42 1.38
1.76 1.67 1.58 1.51 1.47 1.43 1.39 1.36
1.76 1.67 1.60 1.54 1.50 1.45 1.41 1.37
1.82 1.77 1.71 1.64 1.57 1.51 1.46 1.40

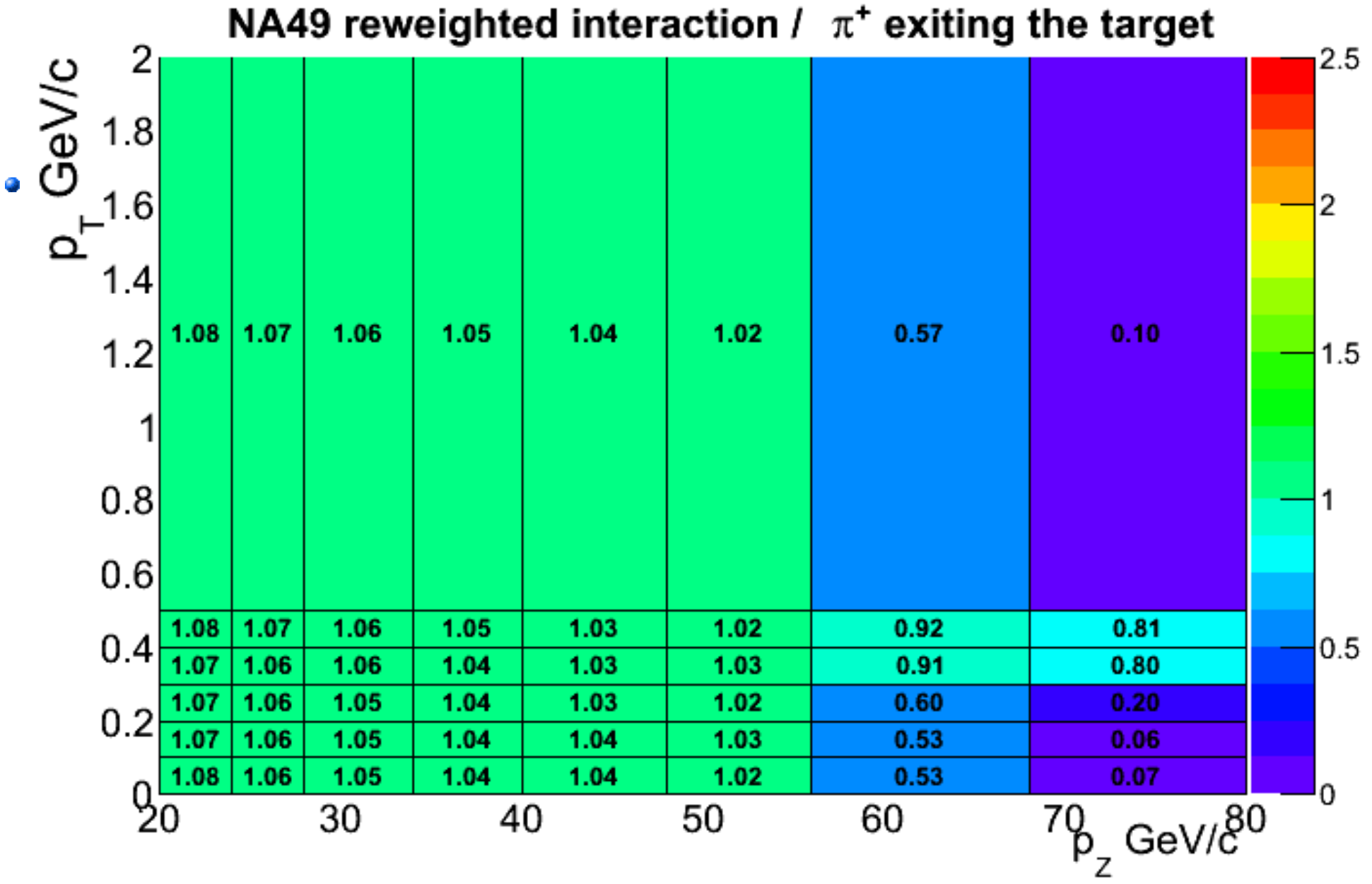
$4<p_z<20$ GeV/c


NA49 reweighted interaction / π+ exiting the target
pT GeV/c
pz GeV/c
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4
6
8
10
12
14
16
18
20
2.5
2
1.5
1
0.5
0
1.01 1.08 1.09 1.09 1.09 1.09 1.09 1.08
1.11 1.12 1.12 1.11 1.11 1.10 1.09 1.08
1.13 1.14 1.13 1.12 1.11 1.11 1.09 1.08
1.15 1.14 1.13 1.12 1.11 1.10 1.09 1.08
1.17 1.16 1.15 1.14 1.13 1.12 1.10 1.09
1.20 1.20 1.20 1.18 1.16 1.13 1.11 1.10

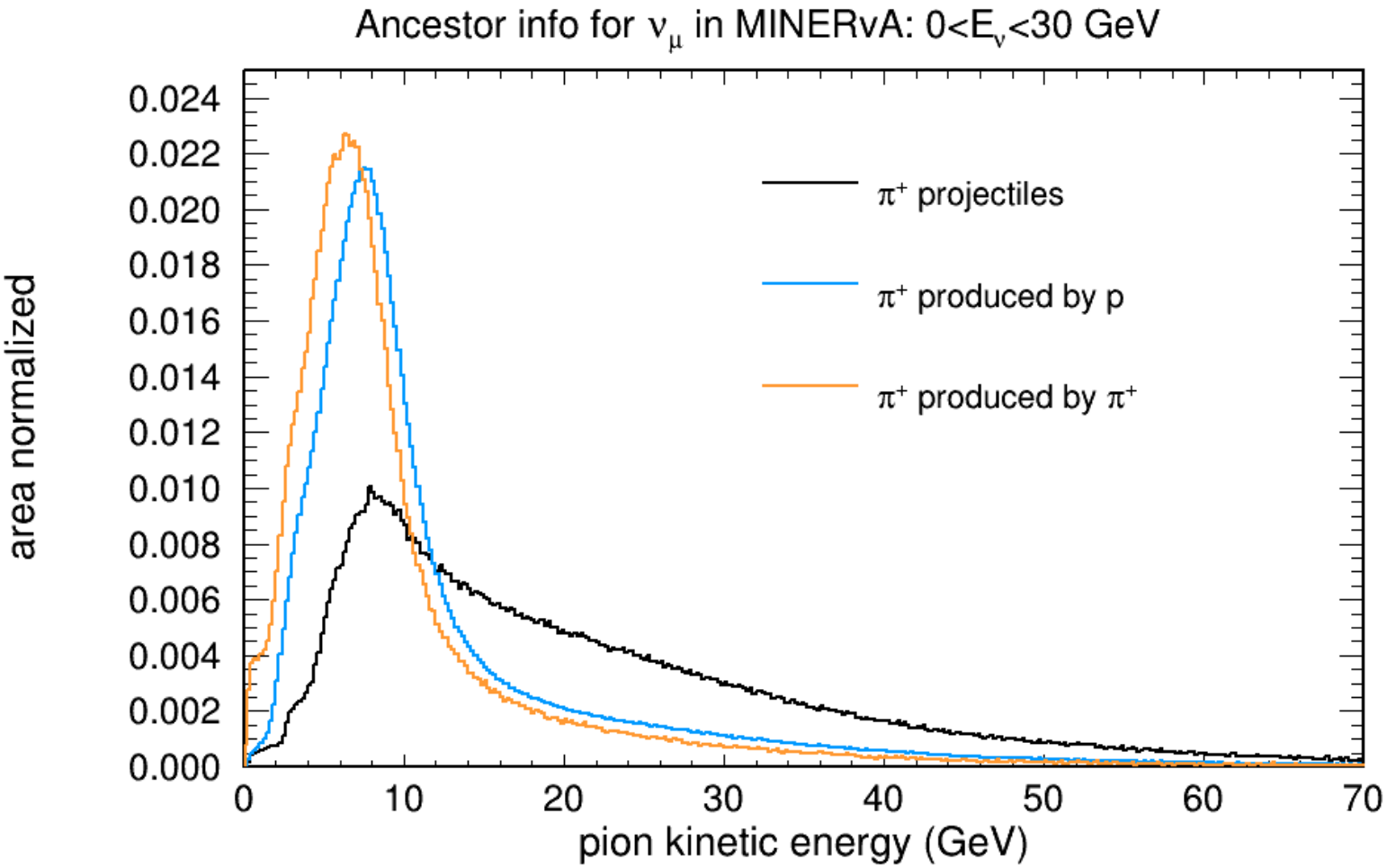
$20<p_z<80$ GeV/c


interaction / π+ exiting the target
p_T GeV/c
p_z GeV/c
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
20
30
40
50
60
70
80
2.5
2
1.5
1
0.5
0
1.43 1.40 1.36 1.33 1.30 1.27 1.25 1.23
1.38 1.35 1.32 1.29 1.27 1.24 1.22 1.21
1.35 1.32 1.30 1.28 1.26 1.24 1.22 1.20
1.33 1.30 1.28 1.27 1.25 1.24 1.23 1.19
1.33 1.30 1.28 1.26 1.26 1.25 1.22 1.20
1.36 1.32 1.29 1.25 1.26 1.23 1.22 1.21

$20<p_z<80$ GeV/c


NA49 reweighted interaction / π+ exiting the target
pT GeV/c
pz GeV/c
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
20
30
40
50
60
70
80
2.5
2
1.5
1
0.5
0
1.08 1.07 1.06 1.05 1.04 1.02 0.57 0.10
1.08 1.07 1.06 1.05 1.03 1.02 0.92 0.81
1.07 1.06 1.06 1.04 1.03 1.03 0.91 0.80
1.07 1.06 1.05 1.04 1.03 1.02 0.60 0.20
1.07 1.06 1.05 1.04 1.04 1.03 0.53 0.06
1.08 1.06 1.05 1.04 1.04 1.02 0.53 0.07

Pion in the Neutrino Chain



- A large number of incident pi+ are in the few 10s of GeVs.
- Those particles are reinteracting to create lower energy pi+.
  What will the effect be of a wrong MC model?

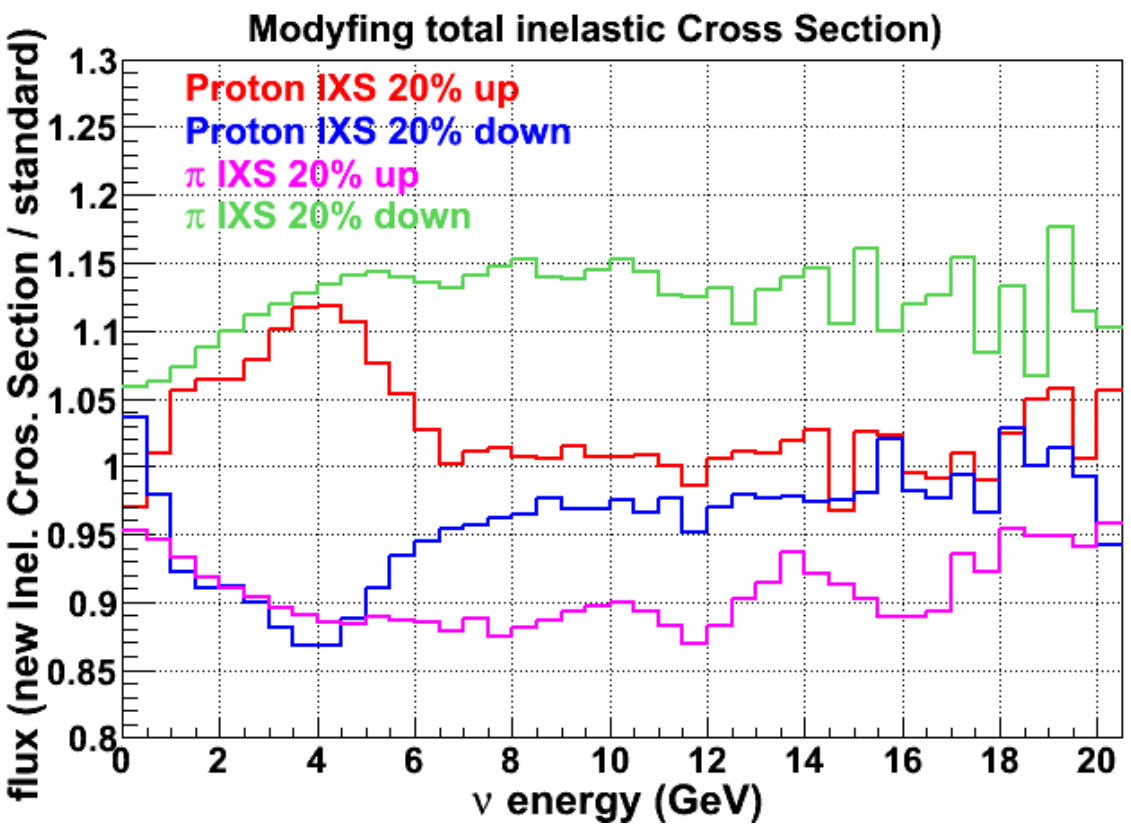
Vary Pion Total Inelastic Cross Section

- We added a knob to geant4 total inelastic cross section (IXS) to see the see the effect on the flux. This allows the cross section to be adjusted without recompiling GEANT.

- As a first approach, we modify the π & proton IXS down and up by 20%.

- The proton effect is due to the focusing.

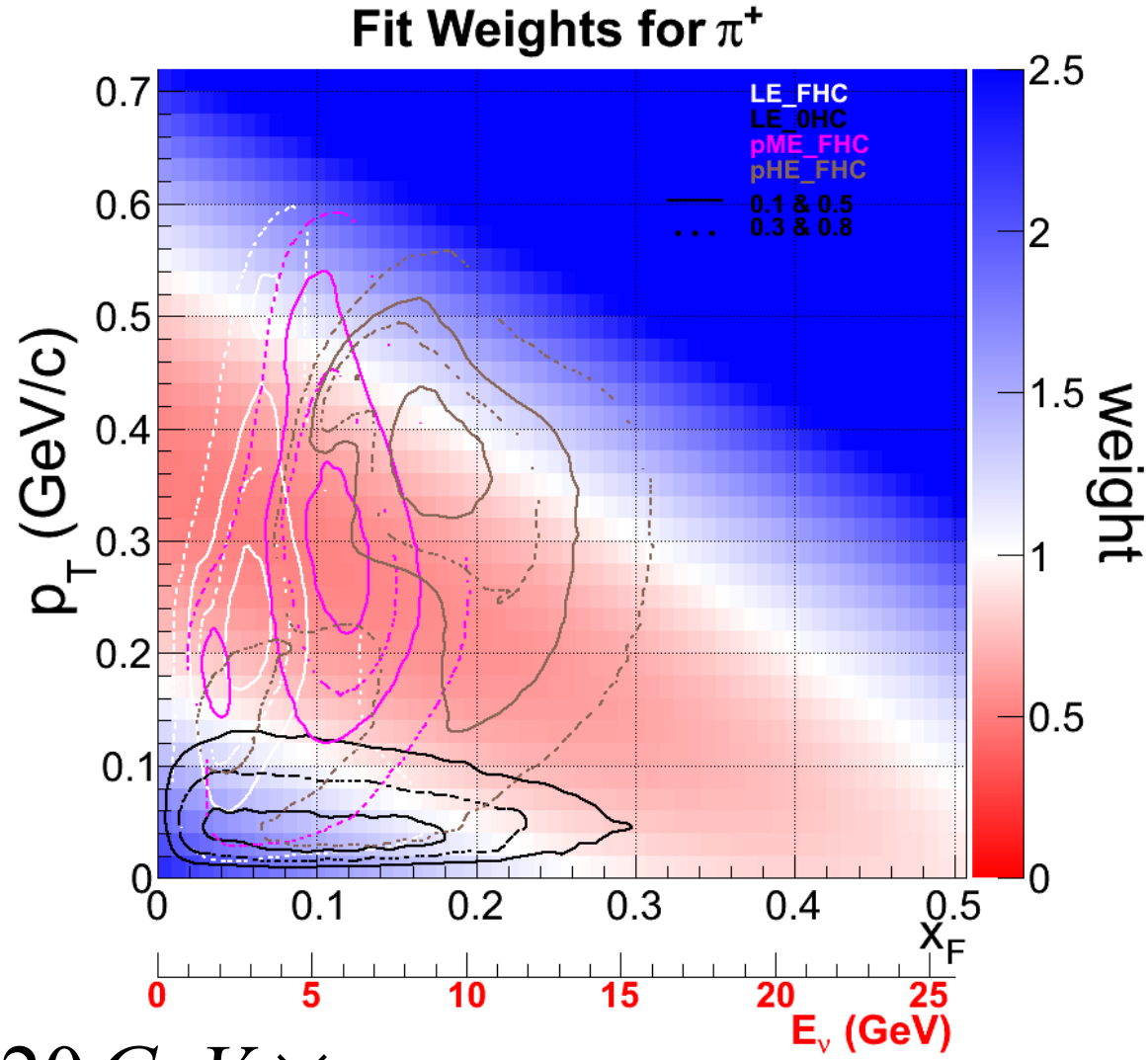
- Increasing π IXS means that more of them will re-interact in the target.



- The effect of the π IXS on the flux is currently under investigation.

A Preliminary Results of the Beam Fit

- In this particular fit, we are using a polynomial function for the weights f(xF,pT).

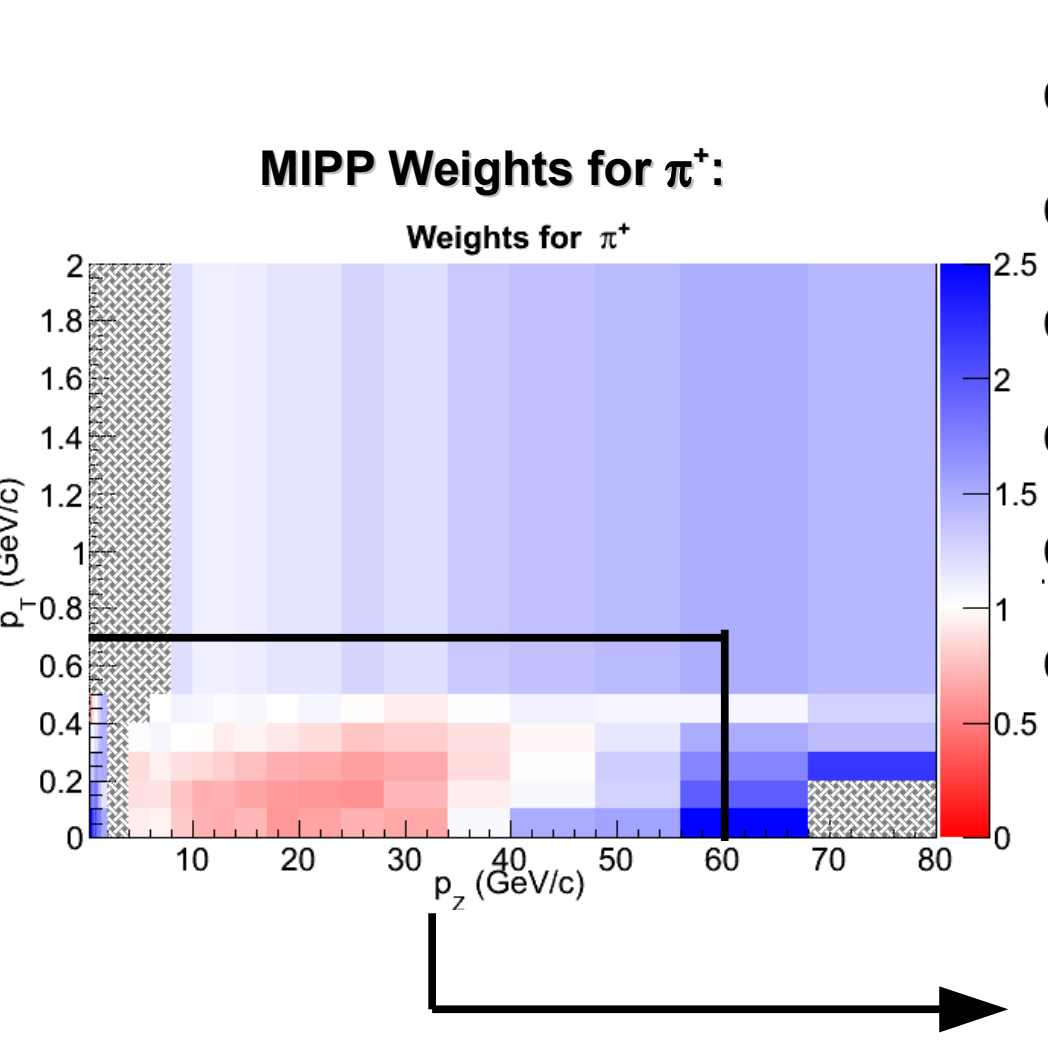


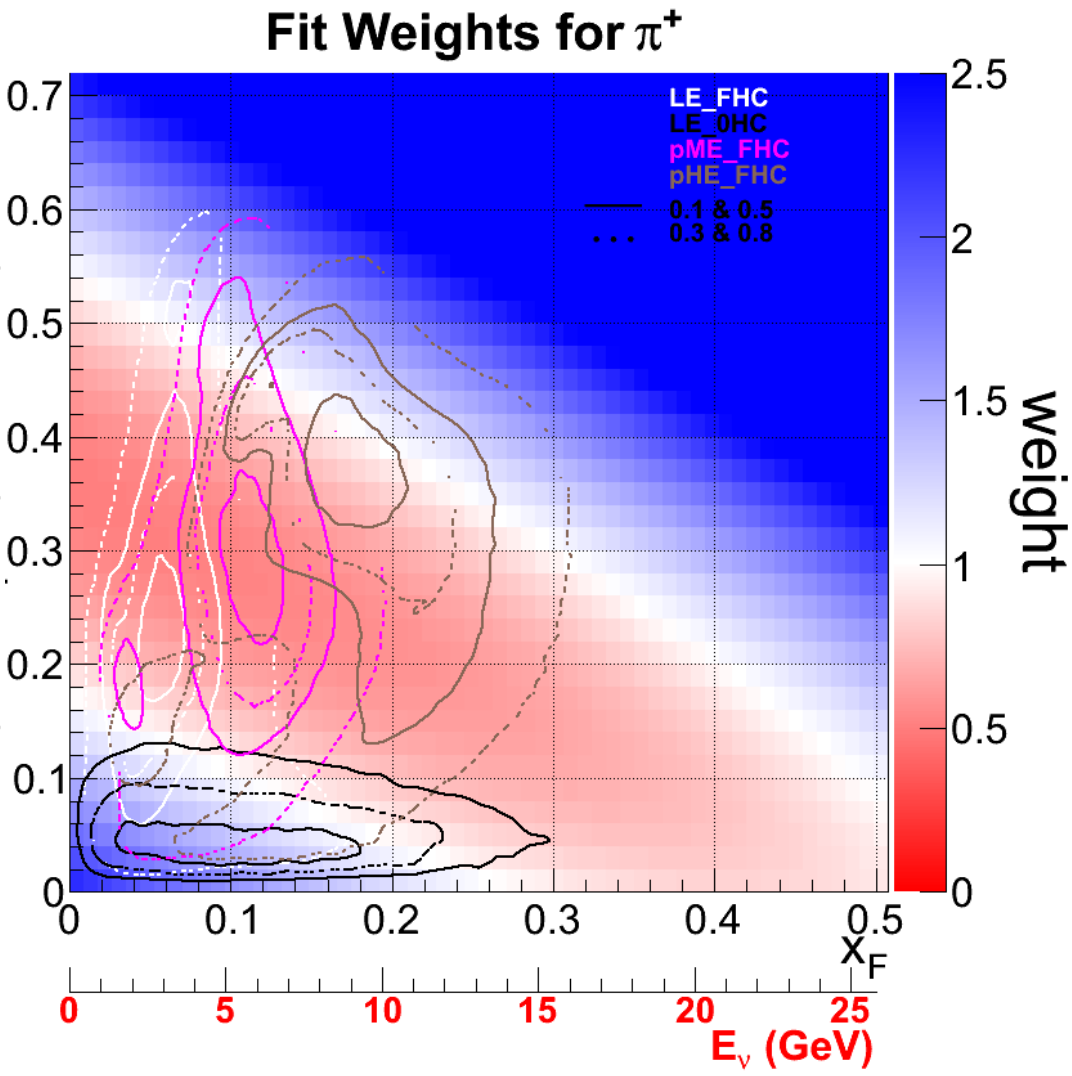
For Minerva:

$$E_\nu \approx 0.43\, E_\pi$$

$$E_\nu \approx 0.43\, E_\pi \approx 0.43 \times 120\, GeV \times x_F$$

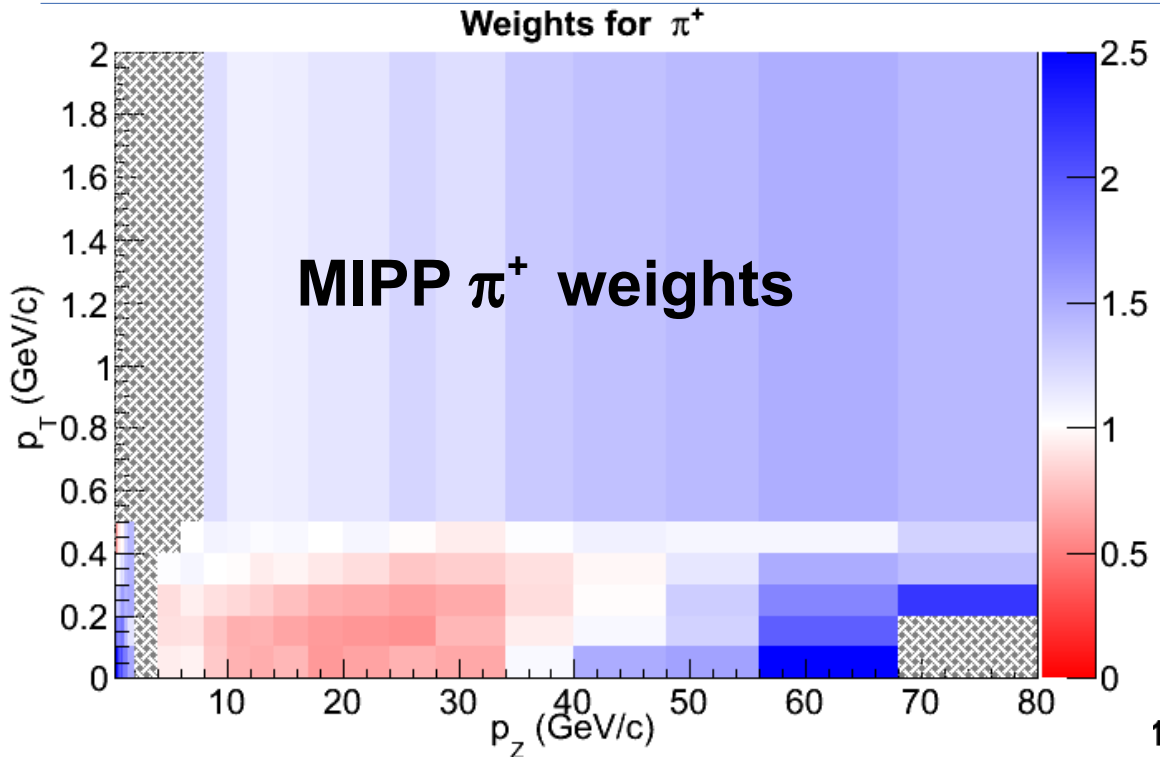
Comparison with MIPP



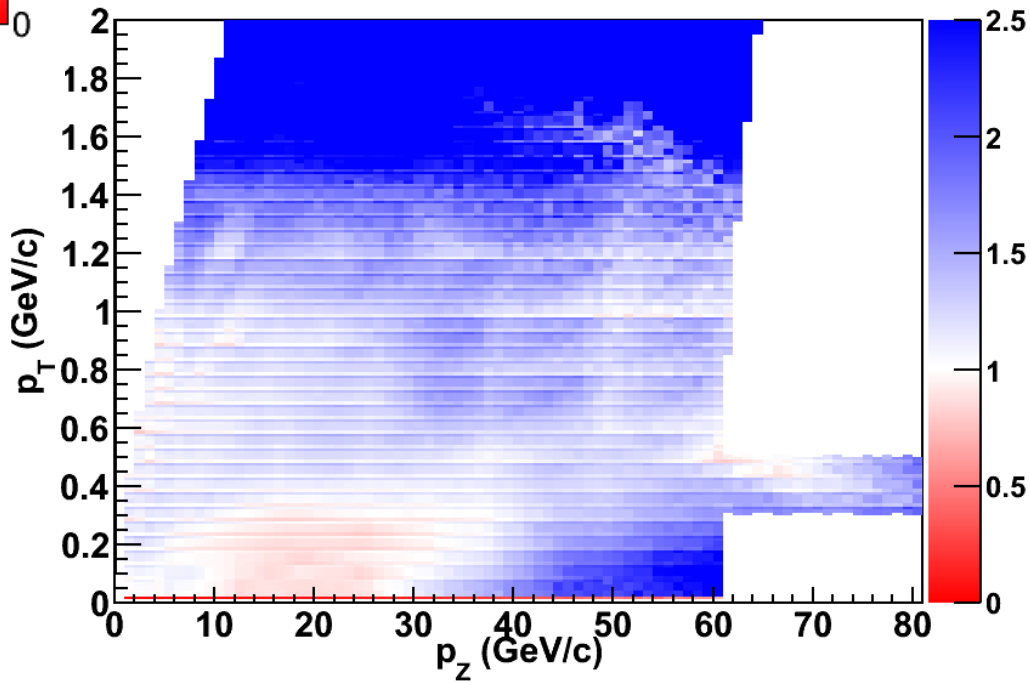


$$x_F \approx p_Z / 120\text{GeV}.$$

Comparing MIPP – thin HP pC @ 120 GeV



NA49 correction at 120 GeV (pC->π^+X)

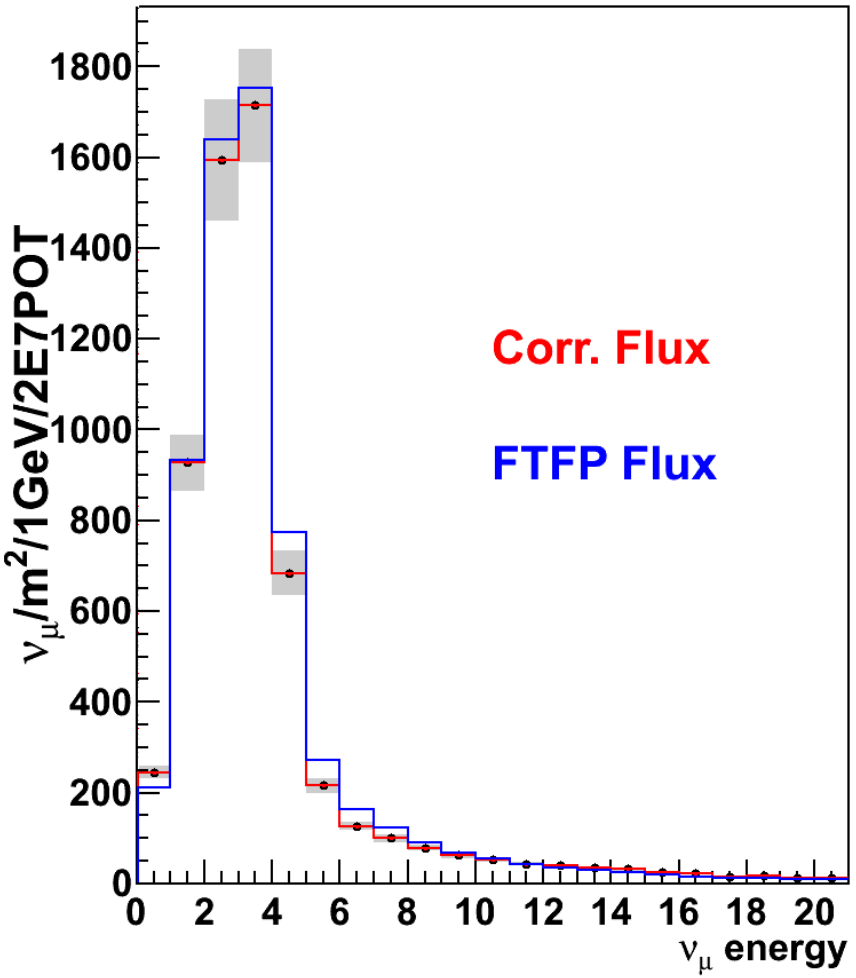


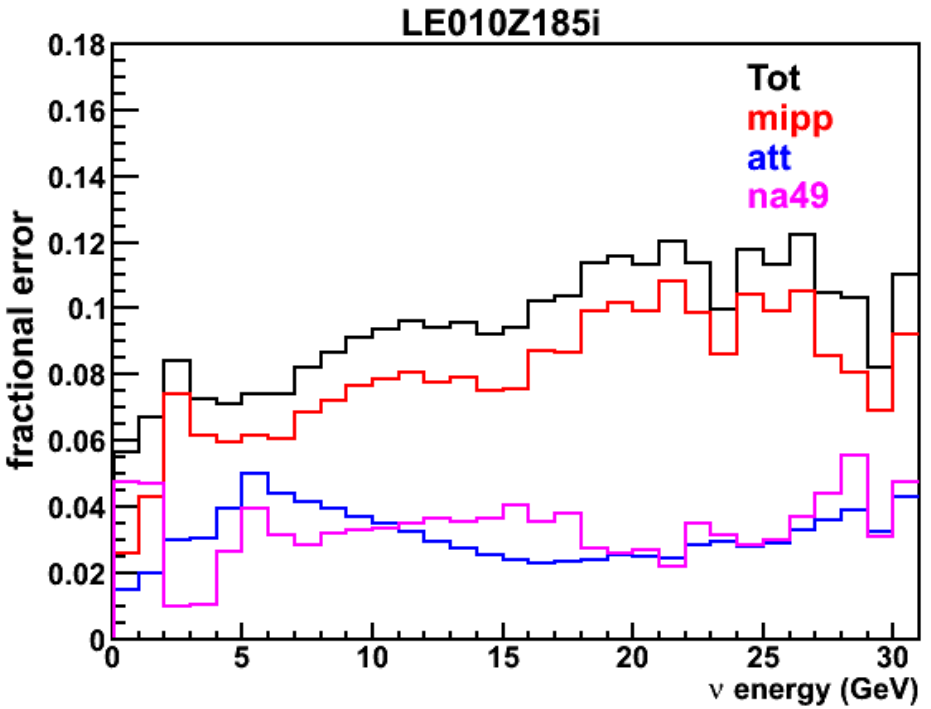
Current Efforts

- We have a comprehensive strategy that includes combining the correction from MIPP replica target yields, thin target production, and the attenuation and absorption of the particle beam.
- **The next slides show the current status of that work.**
  - We follow the following algorithm:

- *Look to see if the event is able to be corrected by MIPP.*
- *Correct for attenuation of the primary particle.*
- *Look for HP correction just outside of the target (for no MIPP events) and the whole neutrino chain when we have no MIPP event.*
- *We apply the multi-universe technique to handle the uncertainties.*

Current Efforts





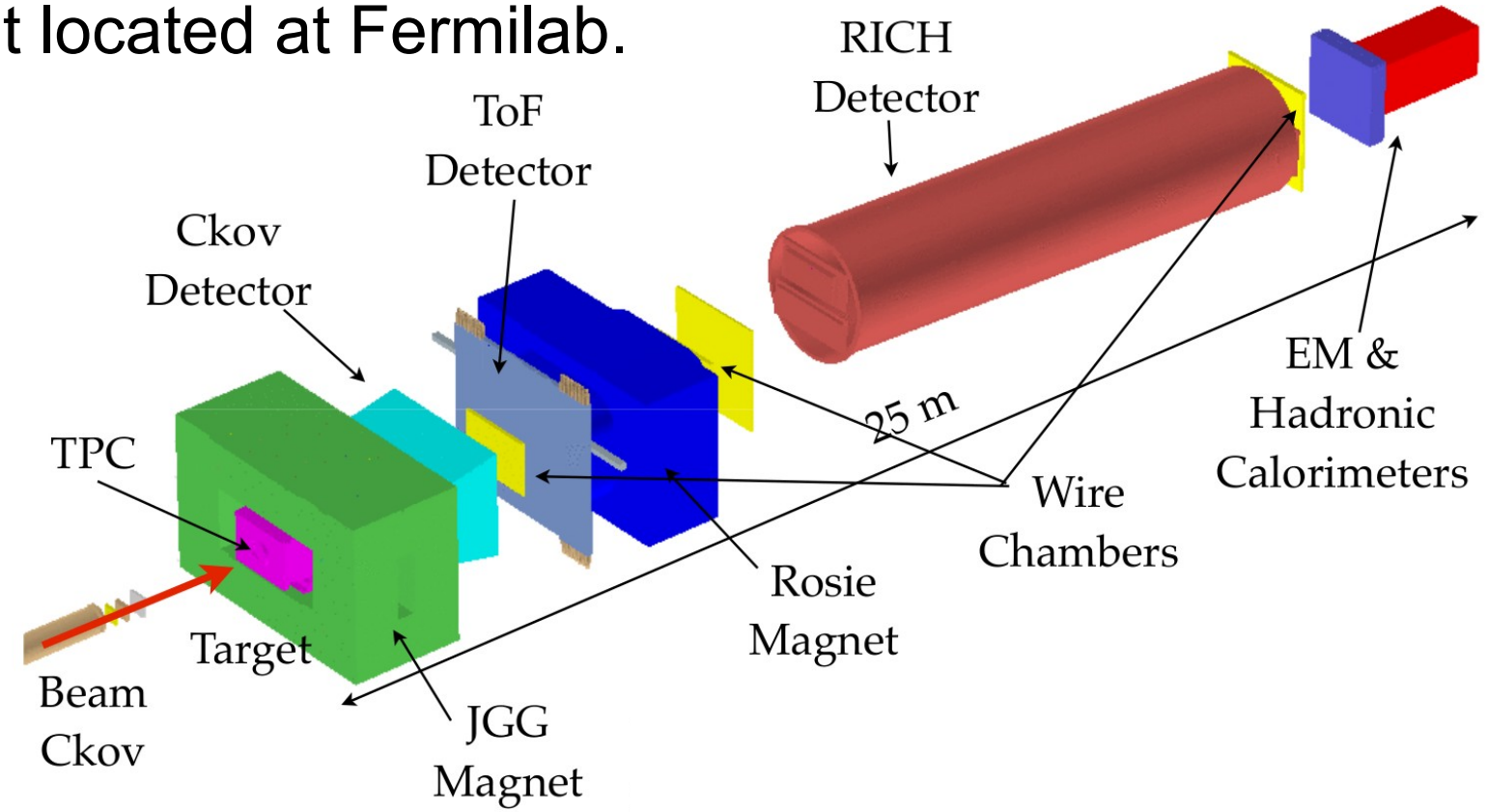
Conclusions

- The first look at the MIPP data to Minerva flux shows a big effect in comparison to the thin target correction.
- We plan to use MIPP data rather than the MIPP parametrization.
- We are on our way to calculate the flux constrained by the all available HP experiments.

backup

MIPP

- Experiment located at Fermilab.



- MIPP measured hadron production data set using different beams and targets (thick and thin).

- MIPP covers a almost the entire kinematic phase space of the HP.

Parametrized Pion Yields

- Jon Paley and Mark Messier parametrized the yield as:

$$\frac{d^2N}{dp_T dp_Z} = p_{inc}\left(A(x) + B(x)\,p_T\right)\exp\left(-C(x)\,p_T^{3/2}\right)$$

Where:

$$A(x) = a_1(1-x)^{a_2}(1+a_3 x)\,x^{-a_4}$$

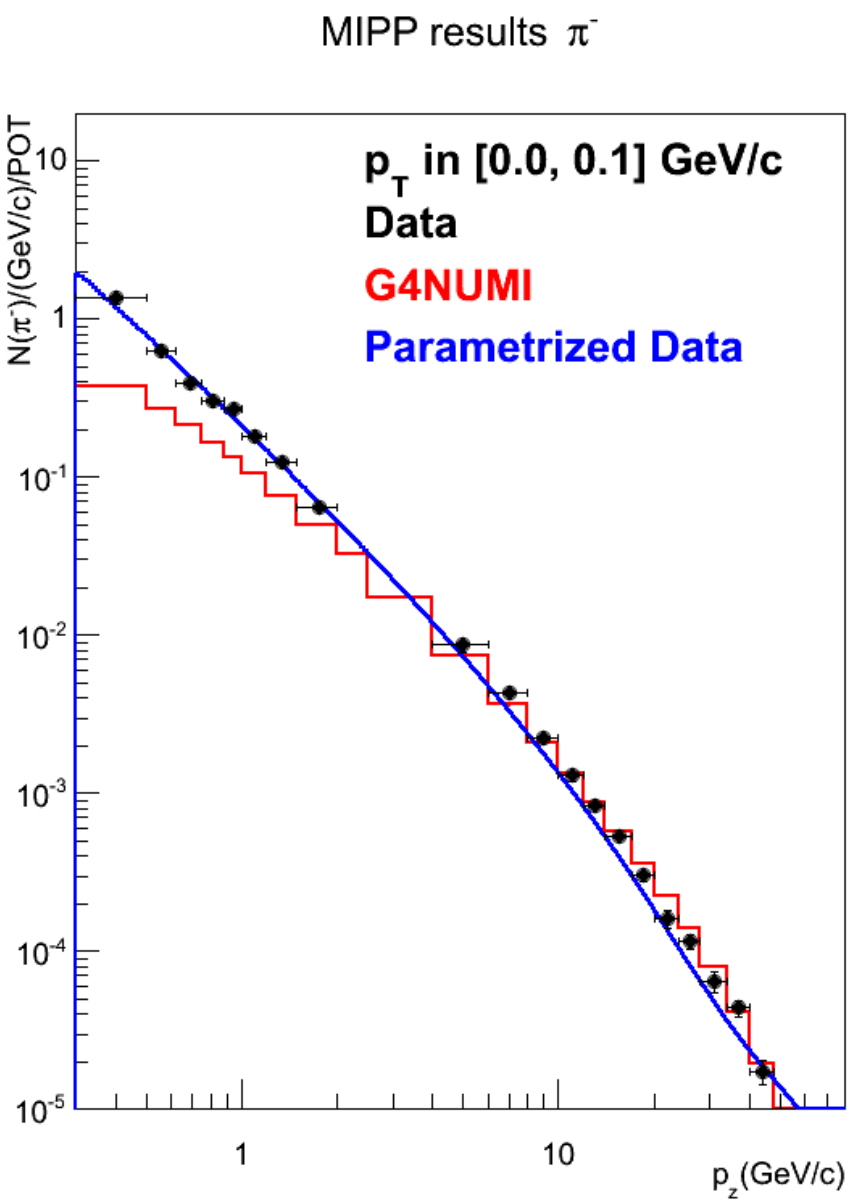
$$B(x) = b_1(1-x)^{b_2}(1+b_3 x)\,x^{-b_4}$$

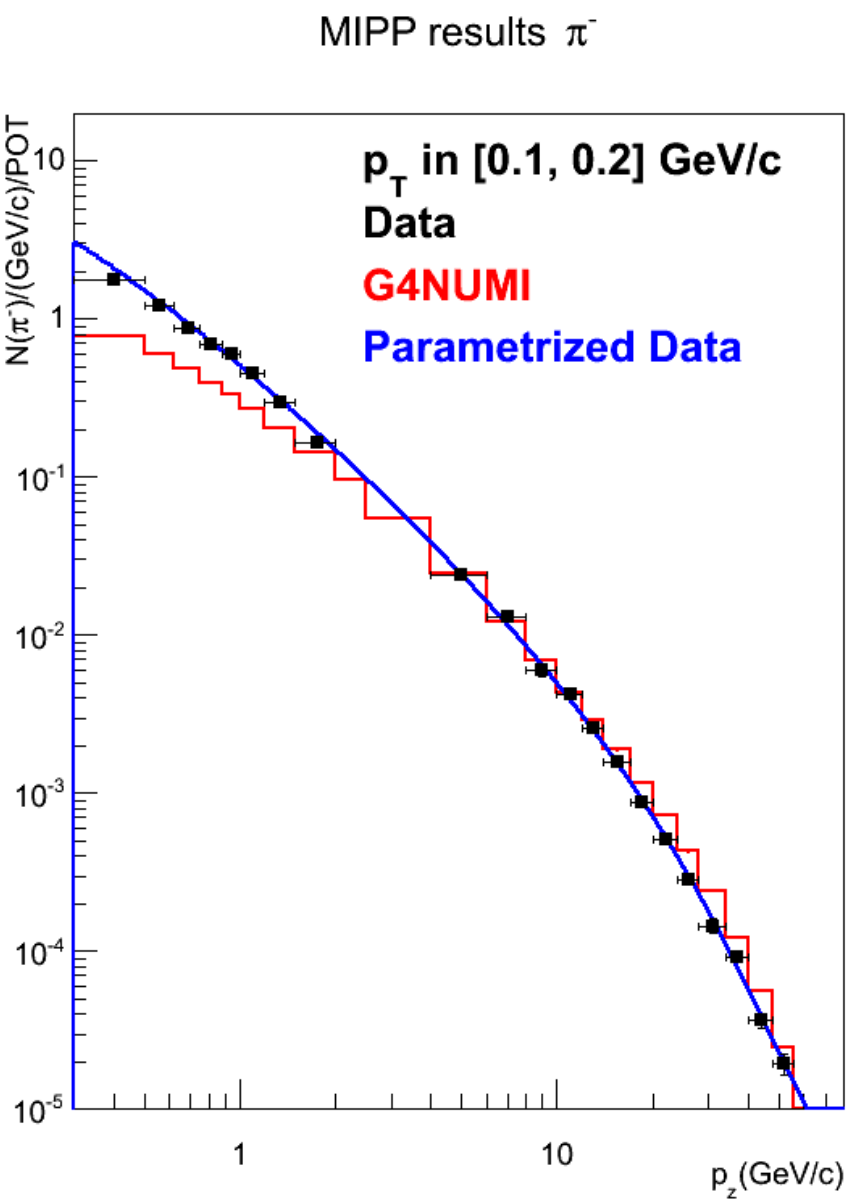
$$C(x) = -c_1/x^{c_2} + c_3$$

$$C(x) = c_{S1}/\exp\left((x+c_{S2})\,c_{S3}\right) + c_{S4}\,x + c_{S5} \qquad x > 0.22$$

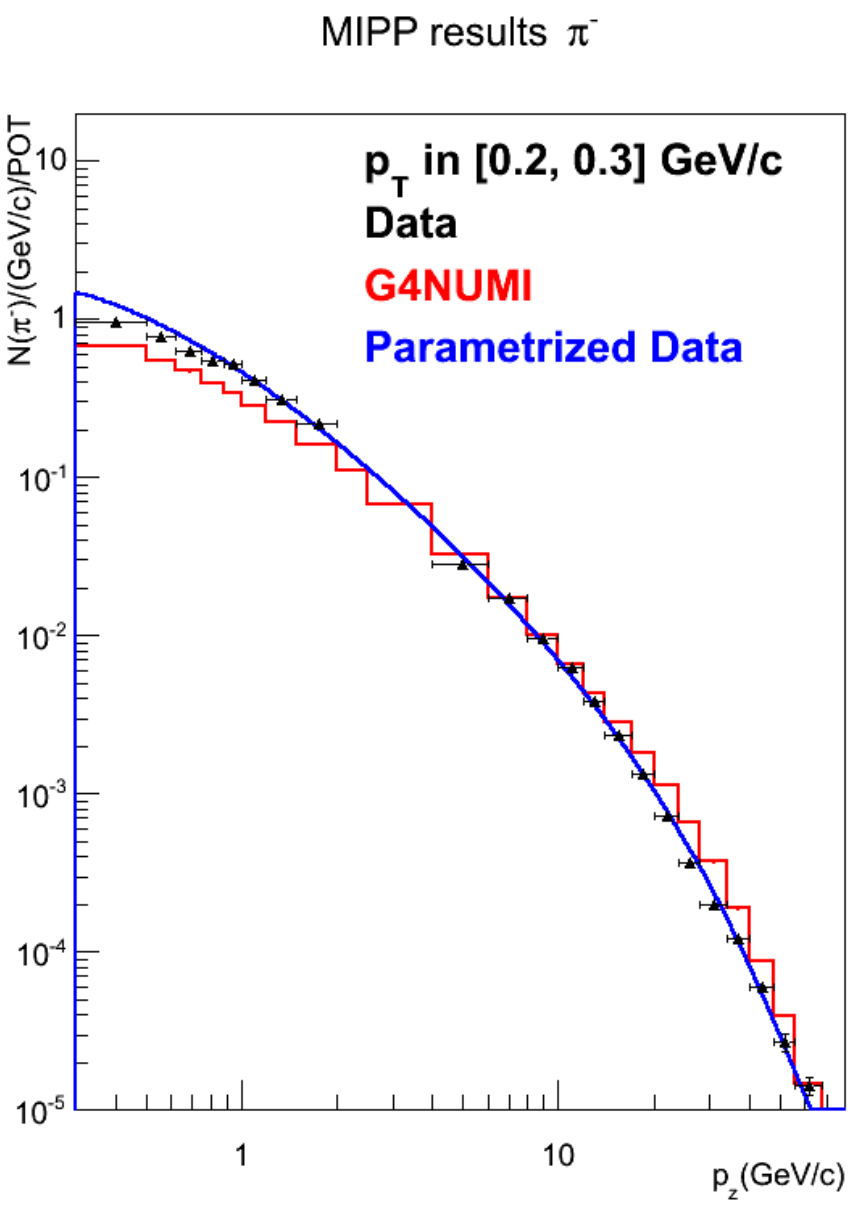
- $x = p_Z/120\,GeV$
- They start the parametrization at p_z = 1GeV/c .

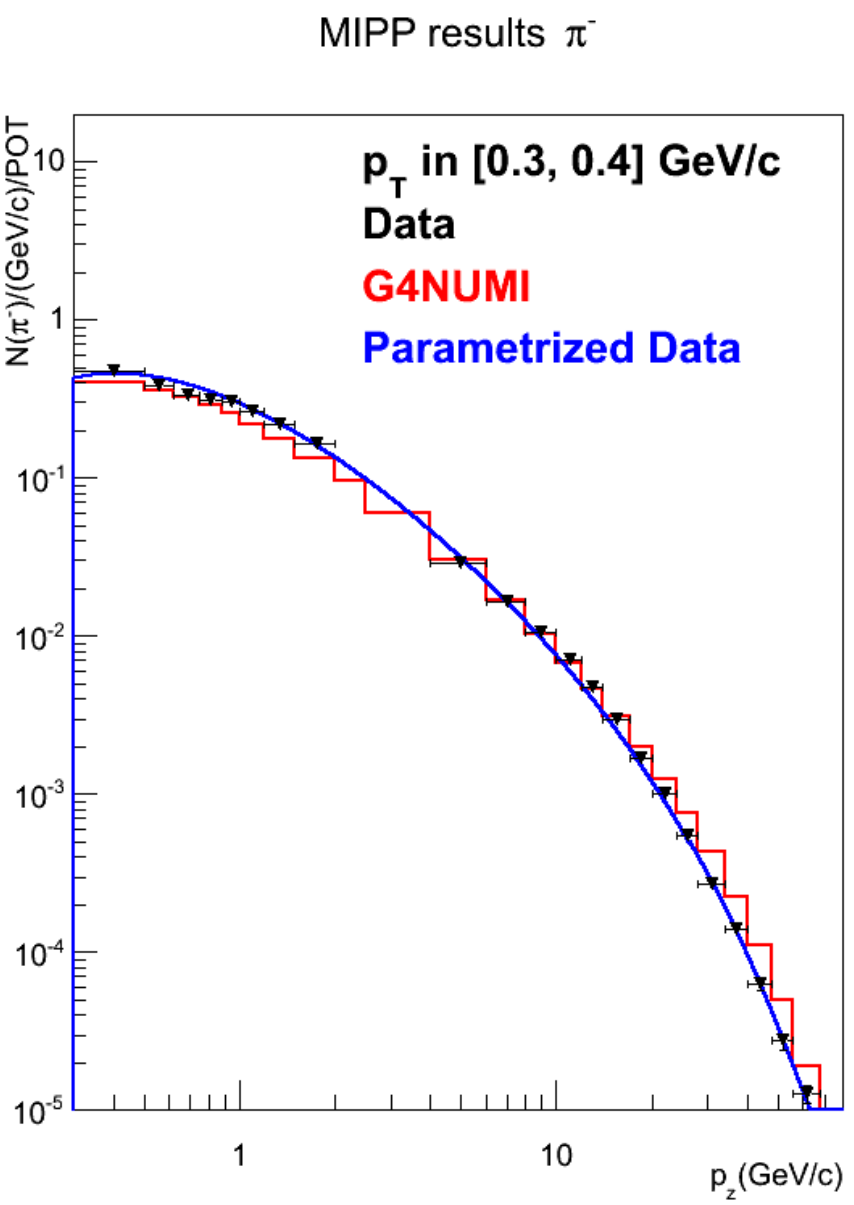
MIPP Data – Parametrization – g4numi comparison



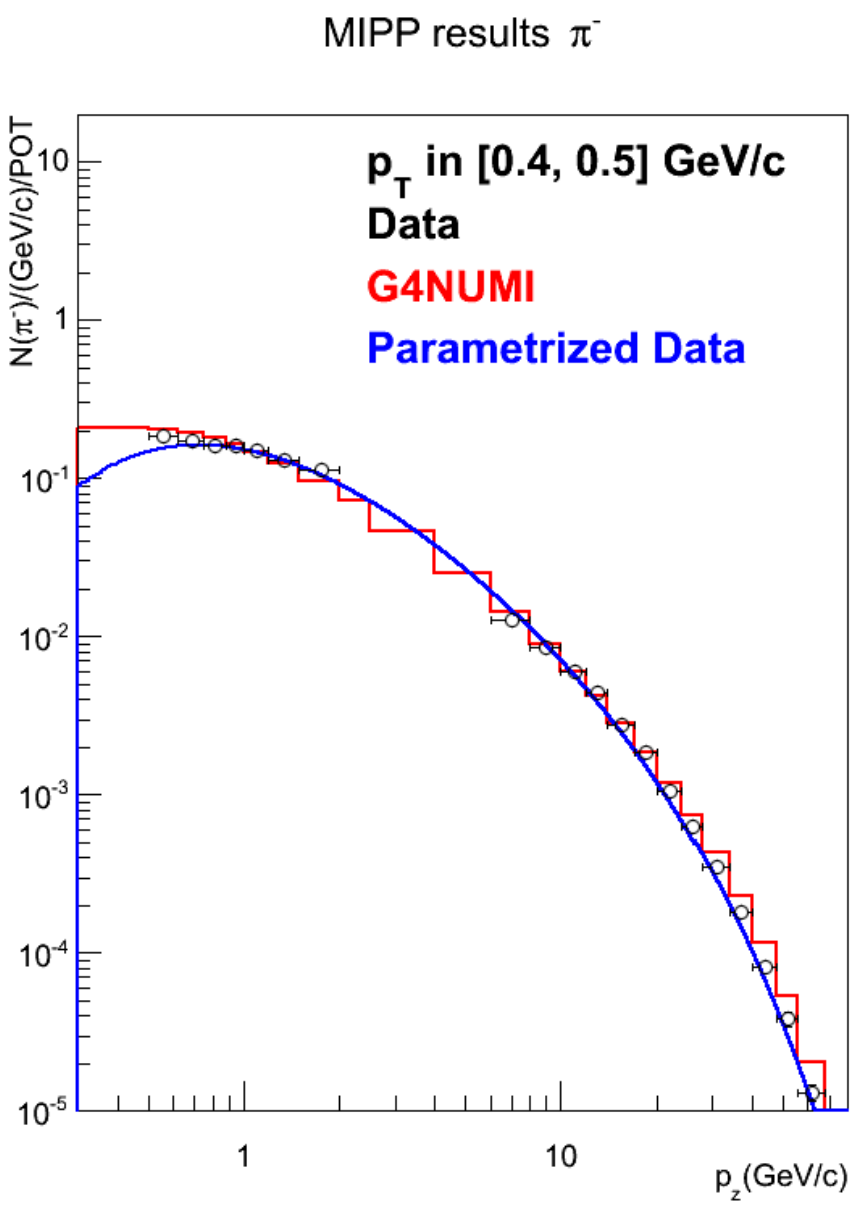


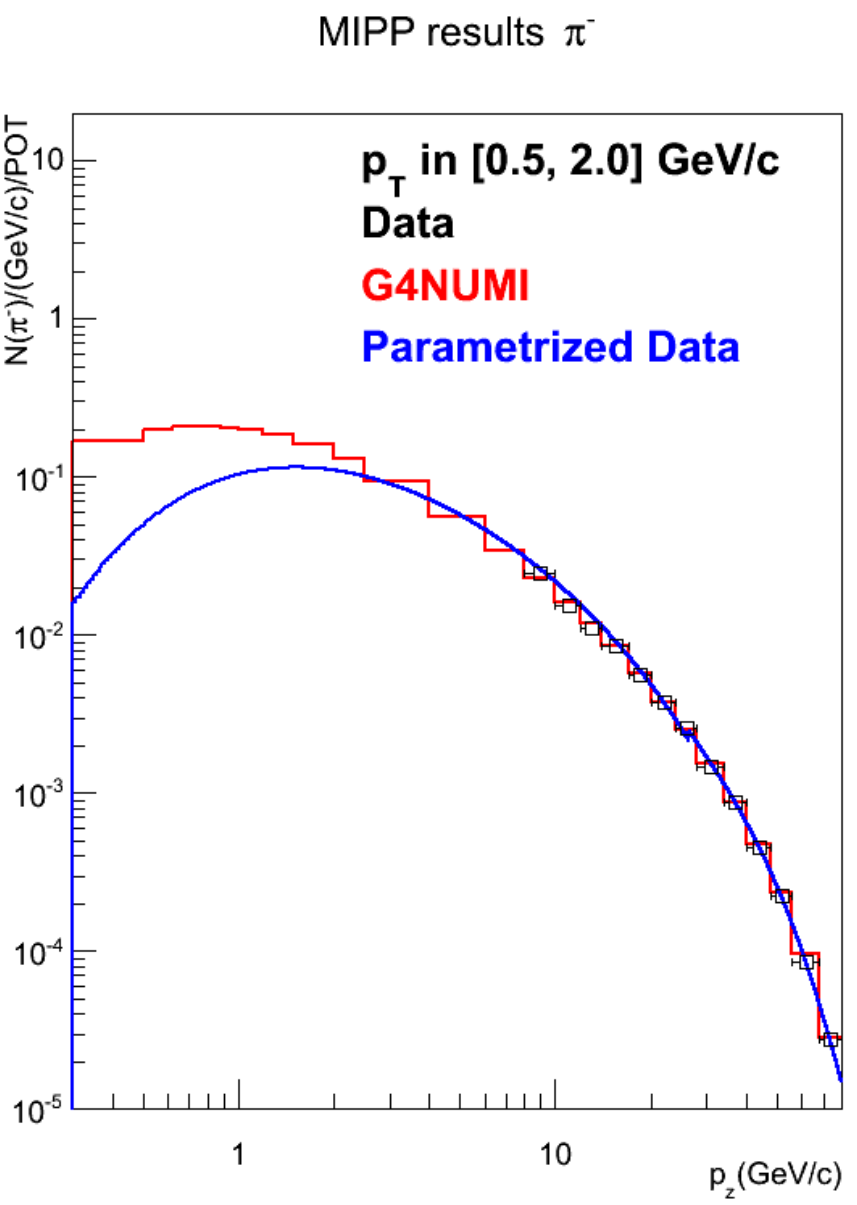
MIPP Data – Parametrization – g4numi comparison



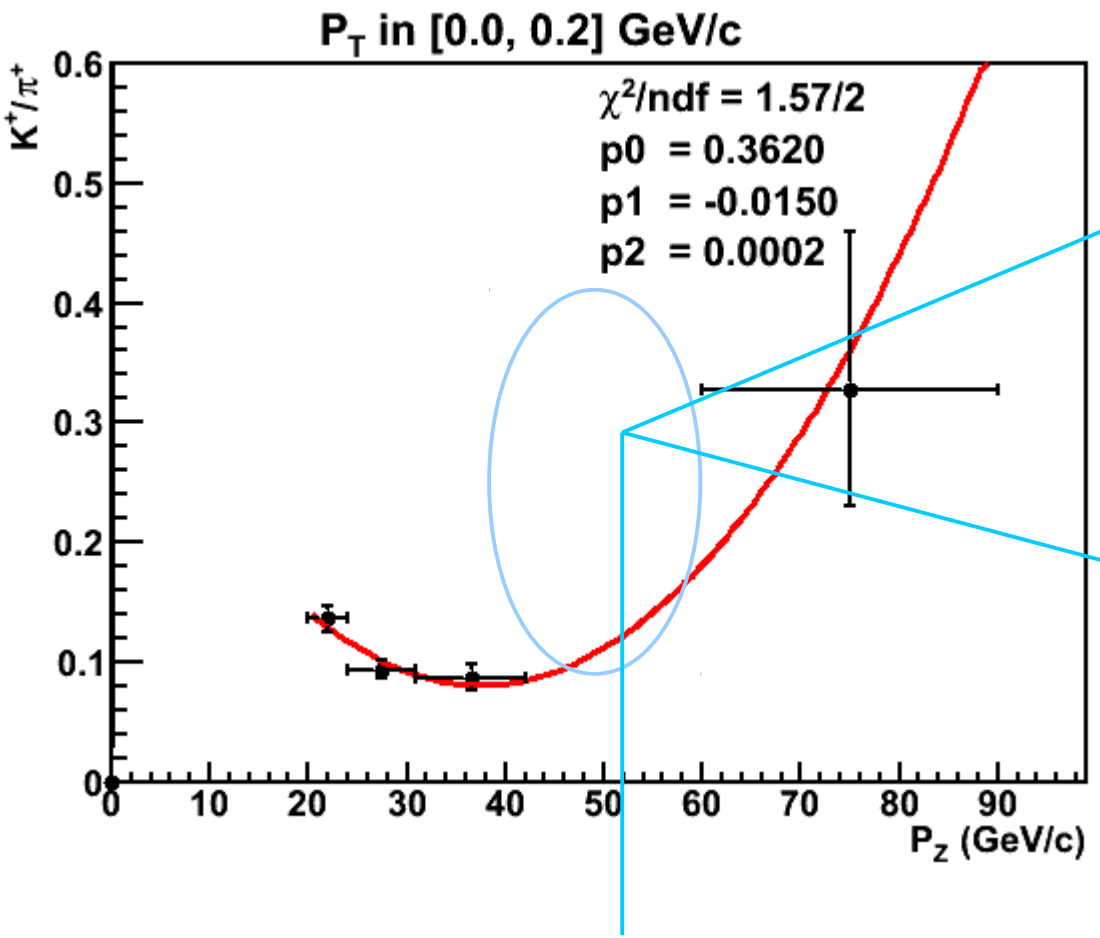


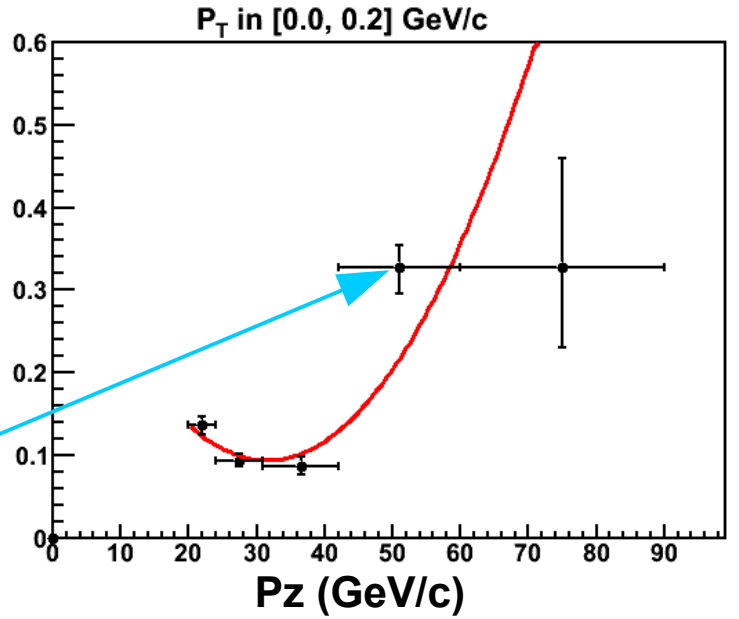
MIPP Data – Parametrization – g4numi comparison

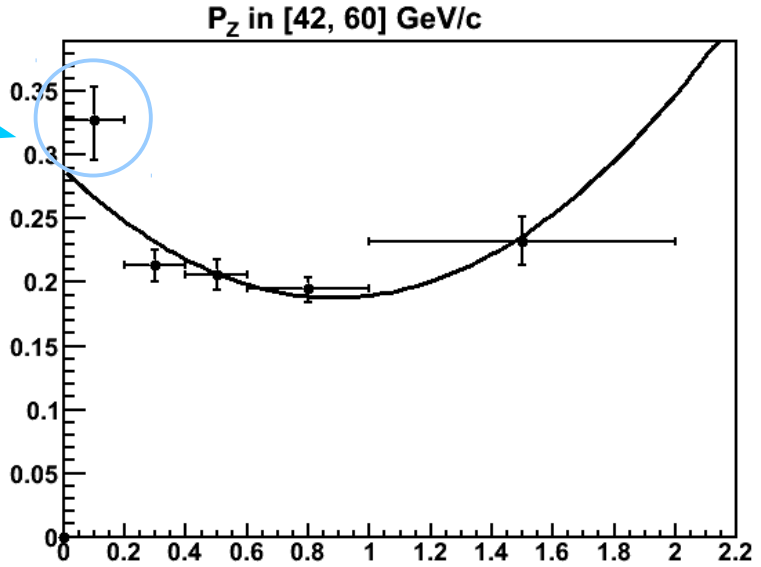




K^+/π^+

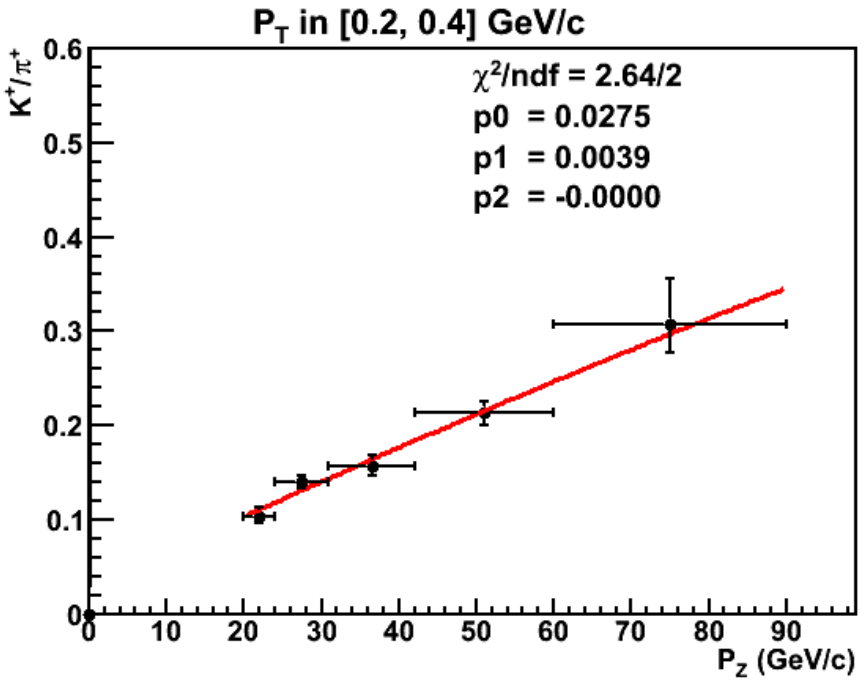


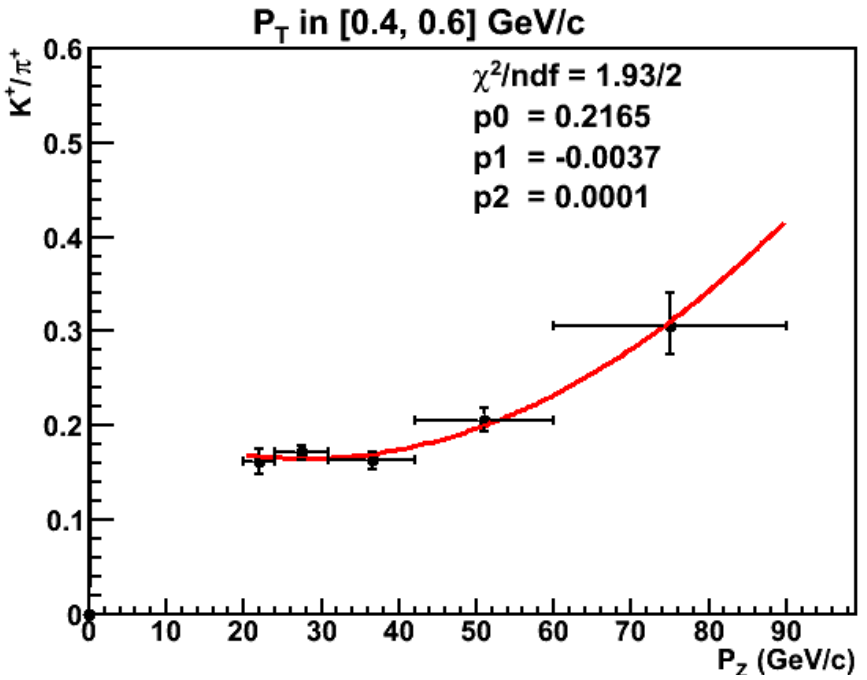


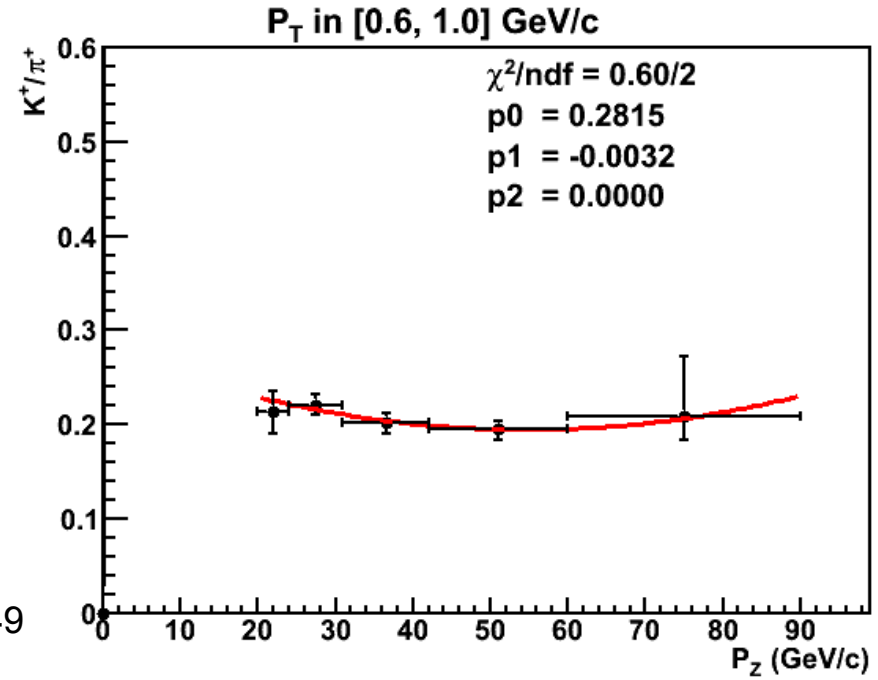


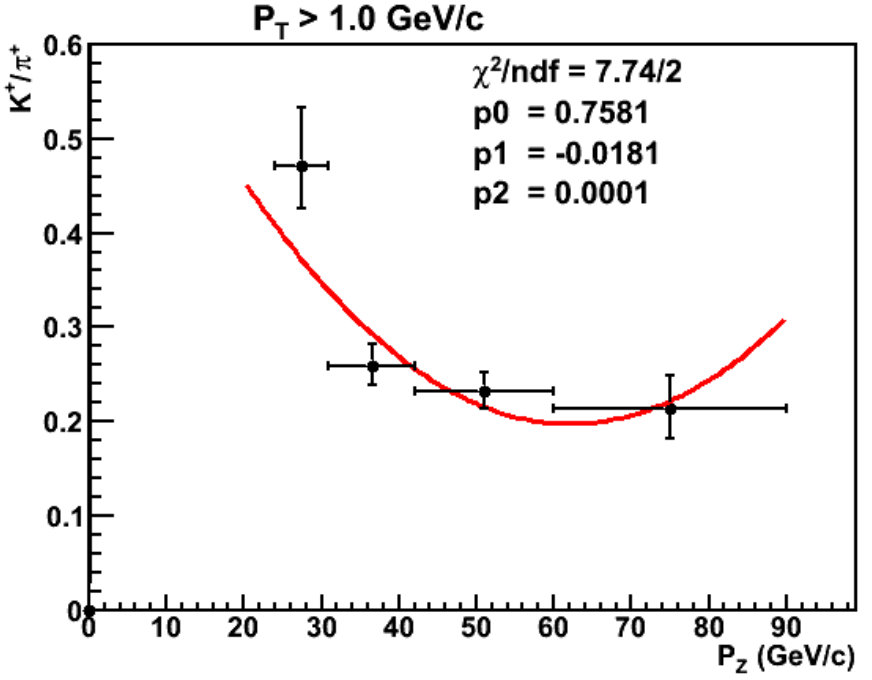
- **Strange point makes the fit go to high for Pz ~ 80 GeV/c**
- **I am not considering this point.**

K^+/π^+

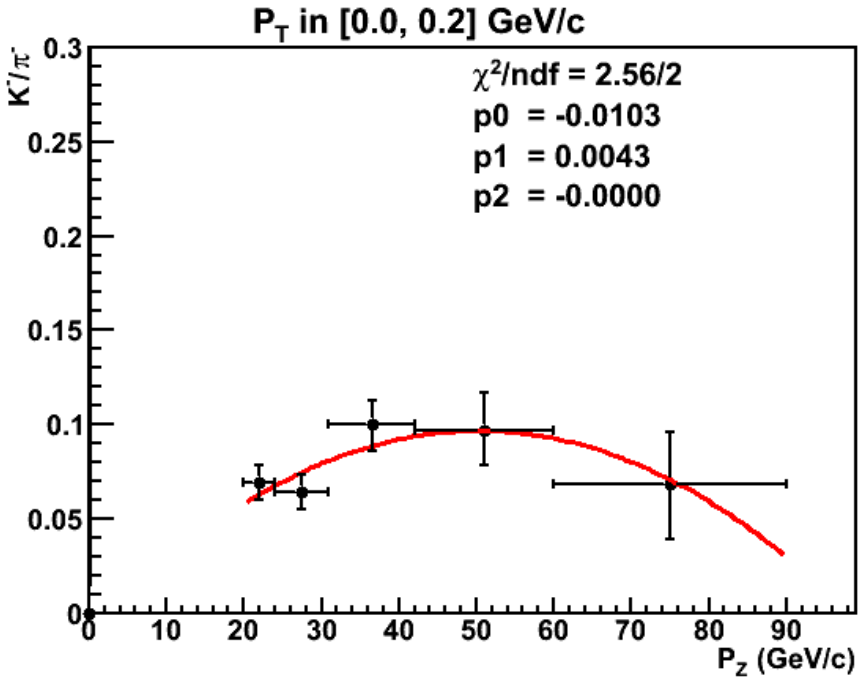

P_T in [0.2, 0.4] GeV/c
χ^2/ndf = 2.64/2
p0 = 0.0275
p1 = 0.0039
p2 = -0.0000
K^+/π^+
P_Z (GeV/c)

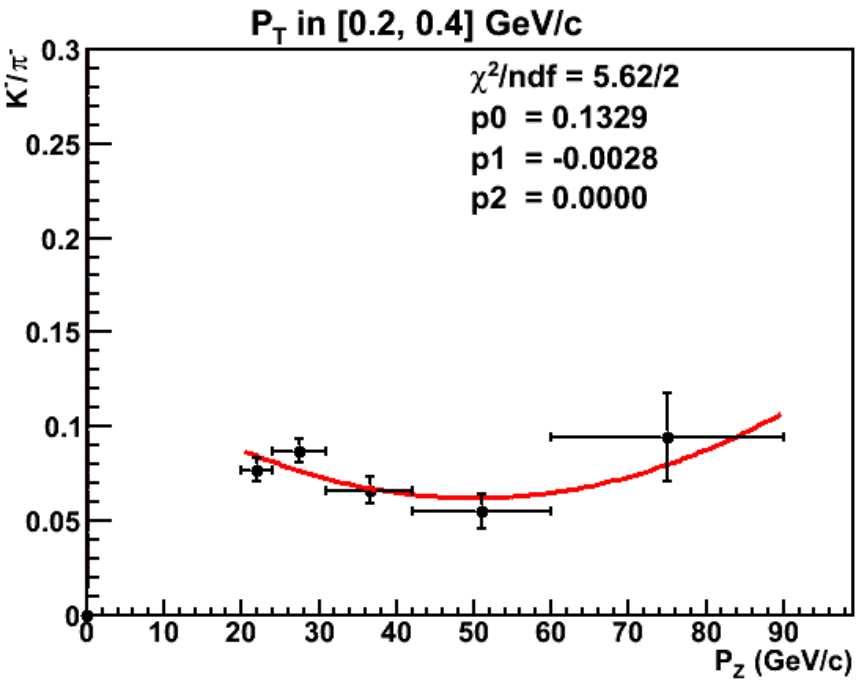

P_T in [0.4, 0.6] GeV/c
χ^2/ndf = 1.93/2
p0 = 0.2165
p1 = -0.0037
p2 = 0.0001
K^+/π^+
P_Z (GeV/c)

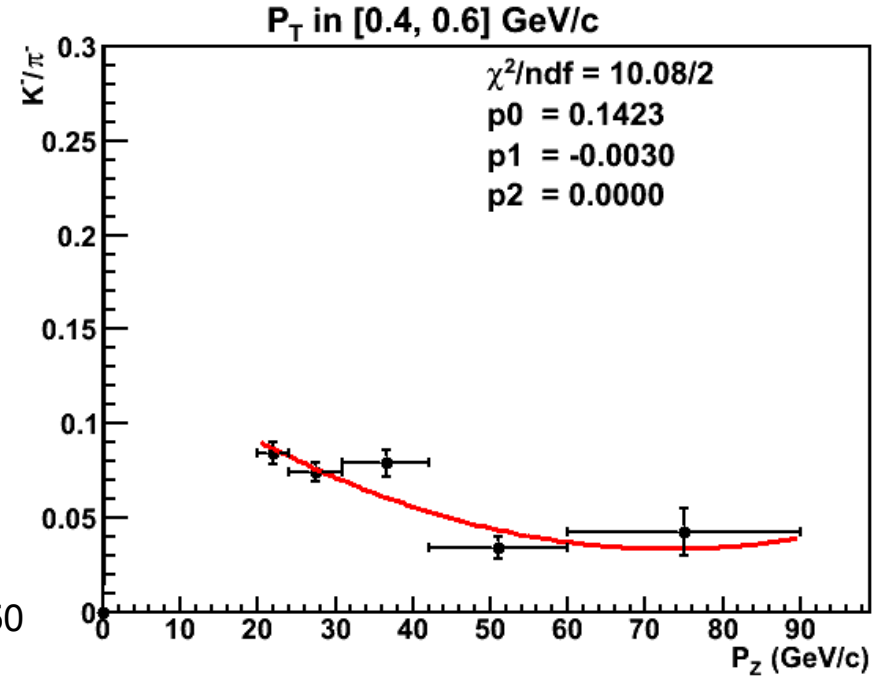

P_T in [0.6, 1.0] GeV/c
χ^2/ndf = 0.60/2
p0 = 0.2815
p1 = -0.0032
p2 = 0.0000
K^+/π^+
P_Z (GeV/c)

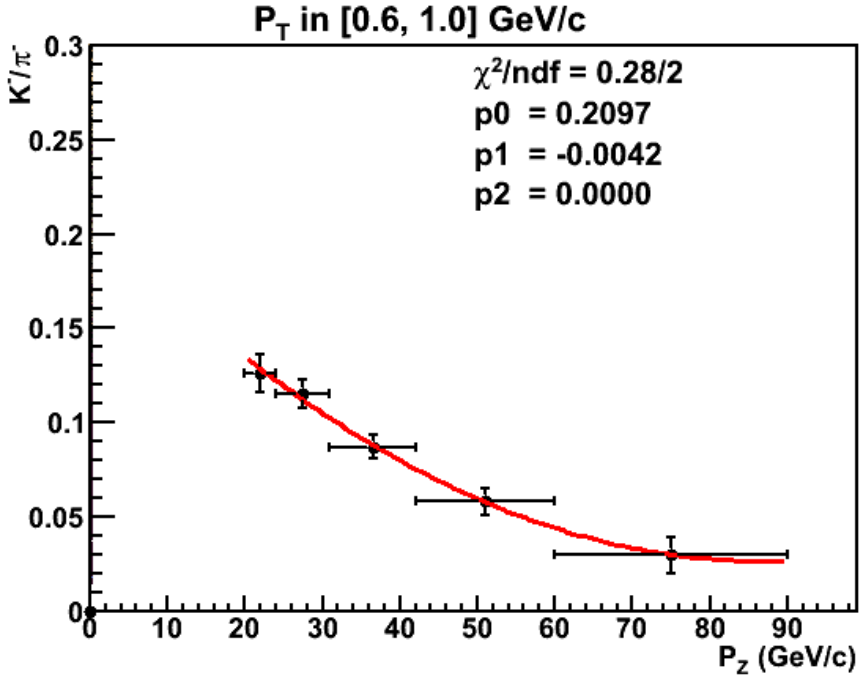

P_T > 1.0 GeV/c
χ^2/ndf = 7.74/2
p0 = 0.7581
p1 = -0.0181
p2 = 0.0001
K^+/π^+
P_Z (GeV/c)

K^-/π^-

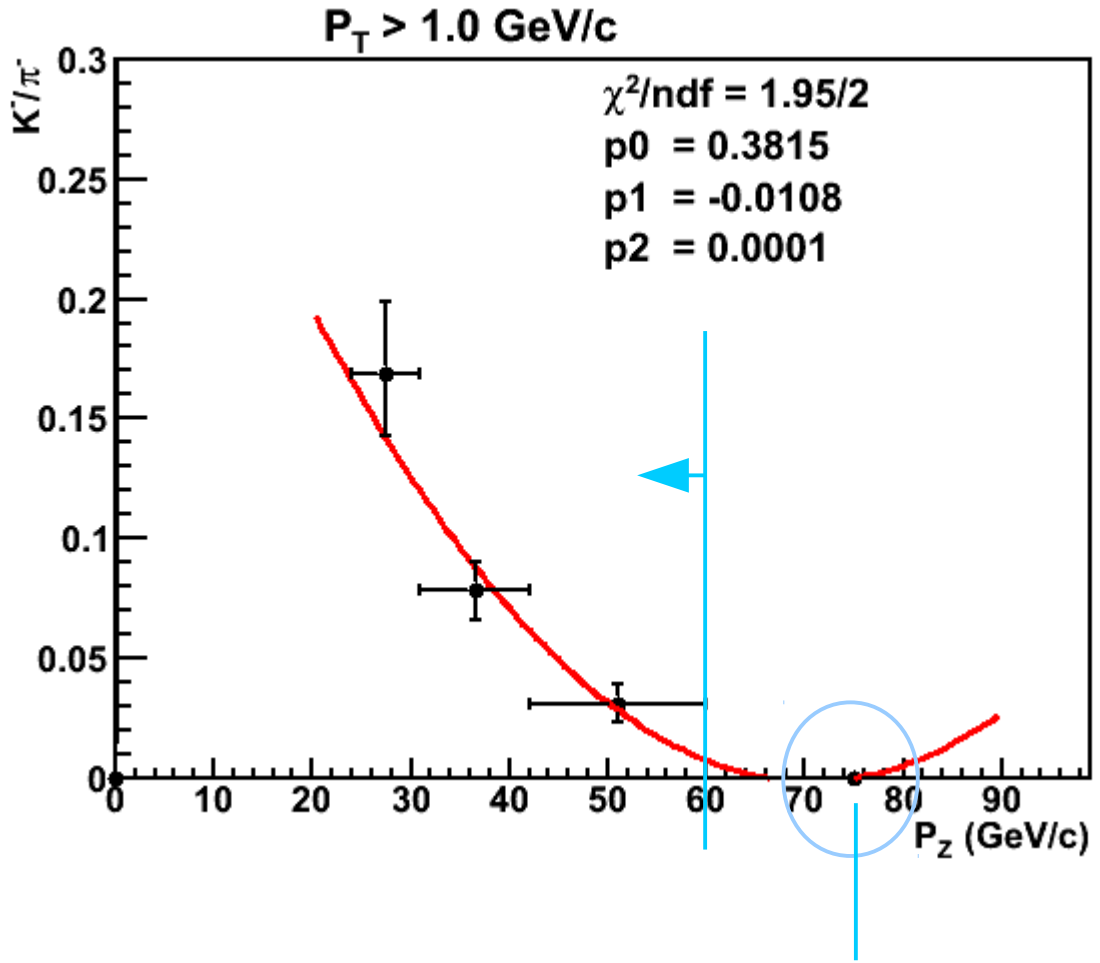

P_T in [0.0, 0.2] GeV/c
χ^2/ndf = 2.56/2
p0 = -0.0103
p1 = 0.0043
p2 = -0.0000
K^-/π^-
P_Z (GeV/c)


P_T in [0.2, 0.4] GeV/c
χ^2/ndf = 5.62/2
p0 = 0.1329
p1 = -0.0028
p2 = 0.0000
K^-/π^-
P_Z (GeV/c)


P_T in [0.4, 0.6] GeV/c
χ^2/ndf = 10.08/2
p0 = 0.1423
p1 = -0.0030
p2 = 0.0000
K^-/π^-
P_Z (GeV/c)

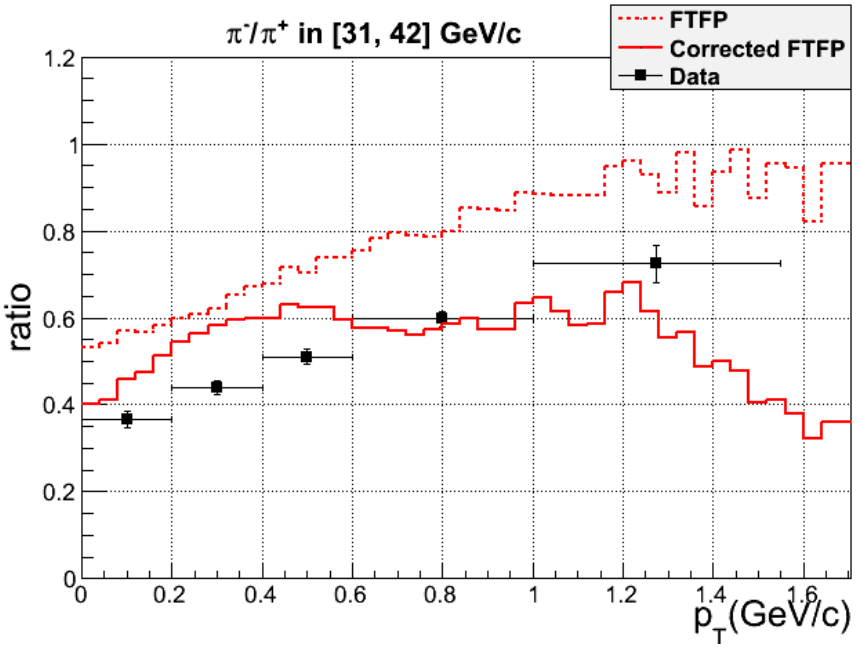

P_T in [0.6, 1.0] GeV/c
χ^2/ndf = 0.28/2
p0 = 0.2097
p1 = -0.0042
p2 = 0.0000
K^-/π^-
P_Z (GeV/c)

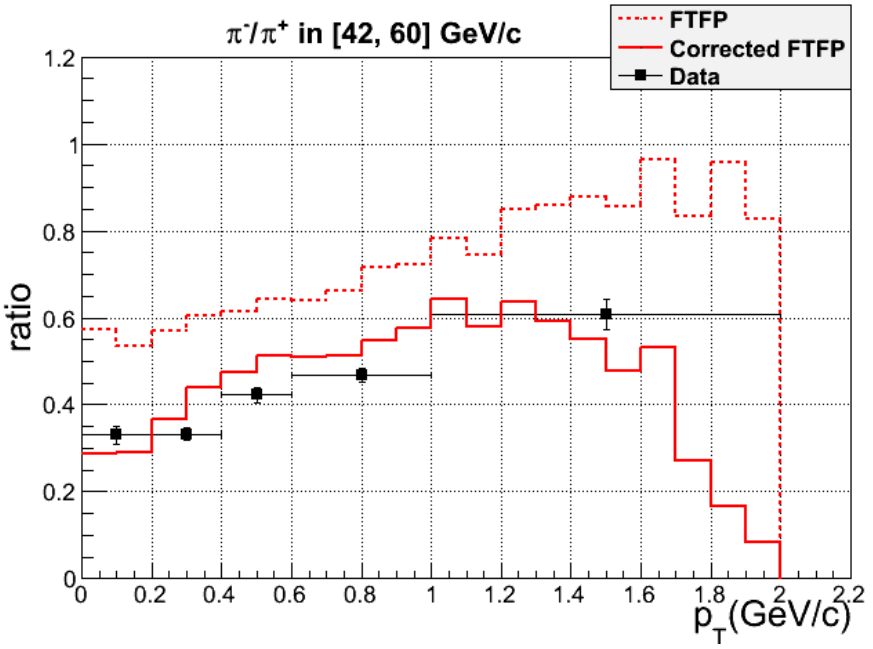
K^-/π^-



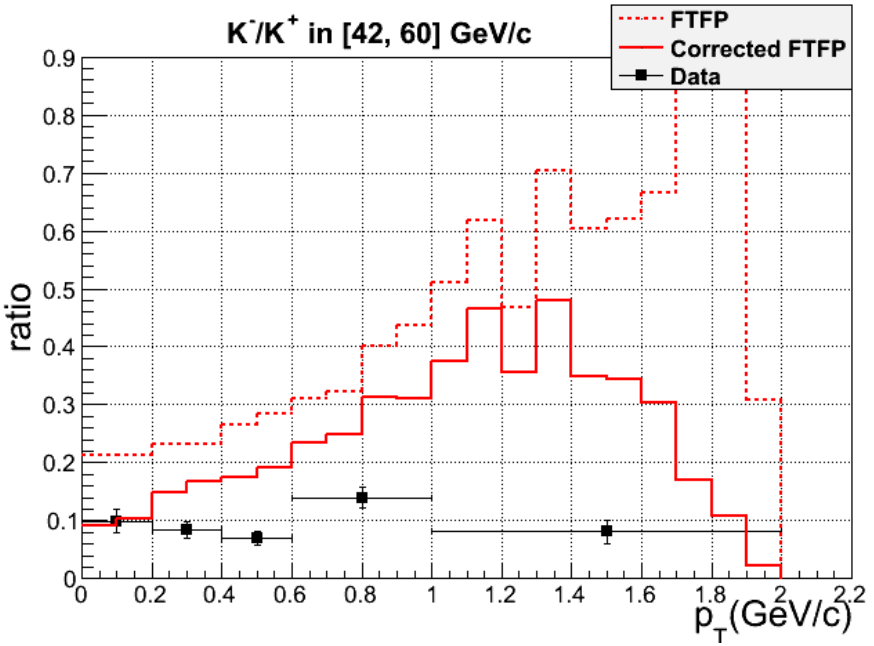
- This is exactly zero.
- I cut in Pz>60 GeV/c.

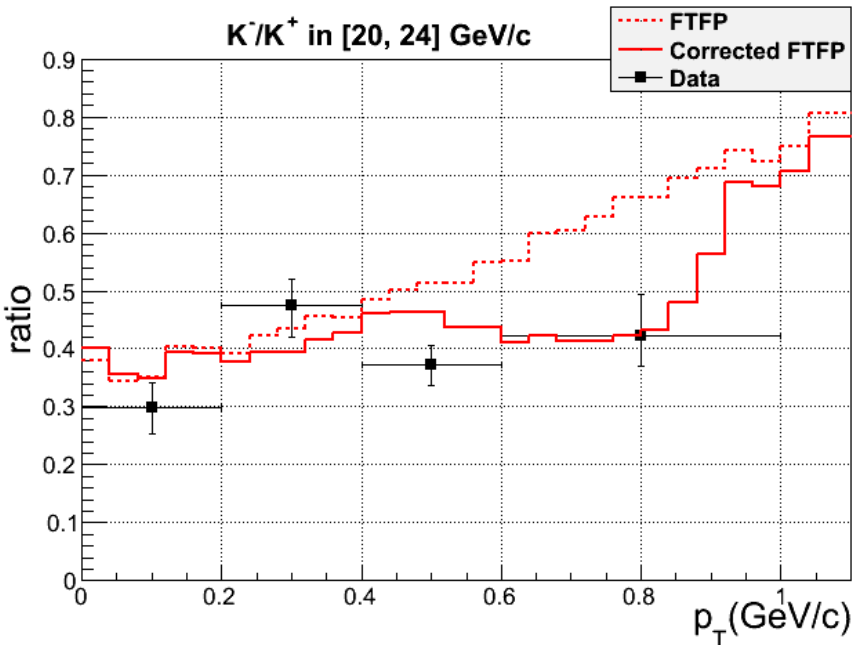
Sharon's thesis ratios comparing with HP correction

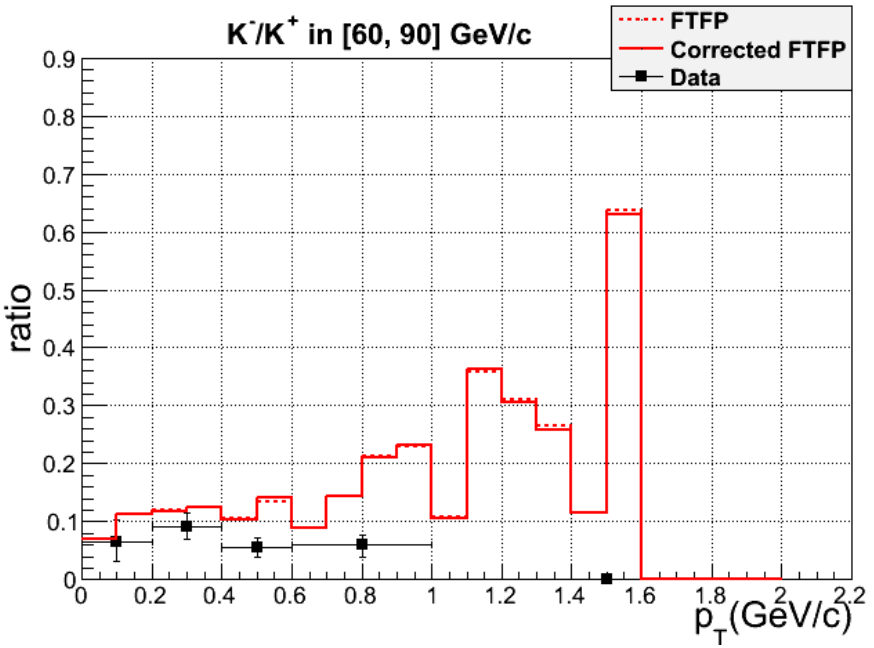


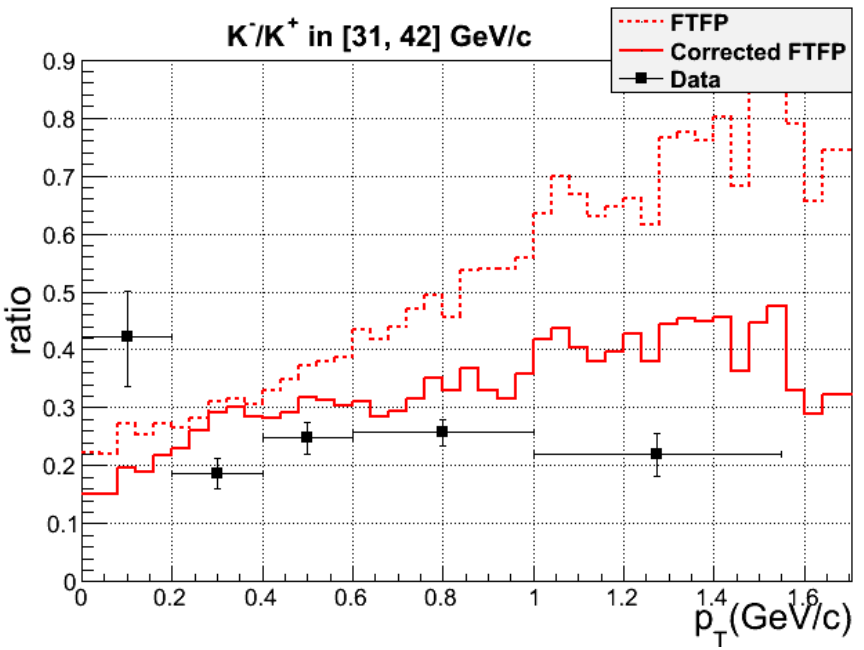


Sharon's thesis ratios comparing with thin target HP correction

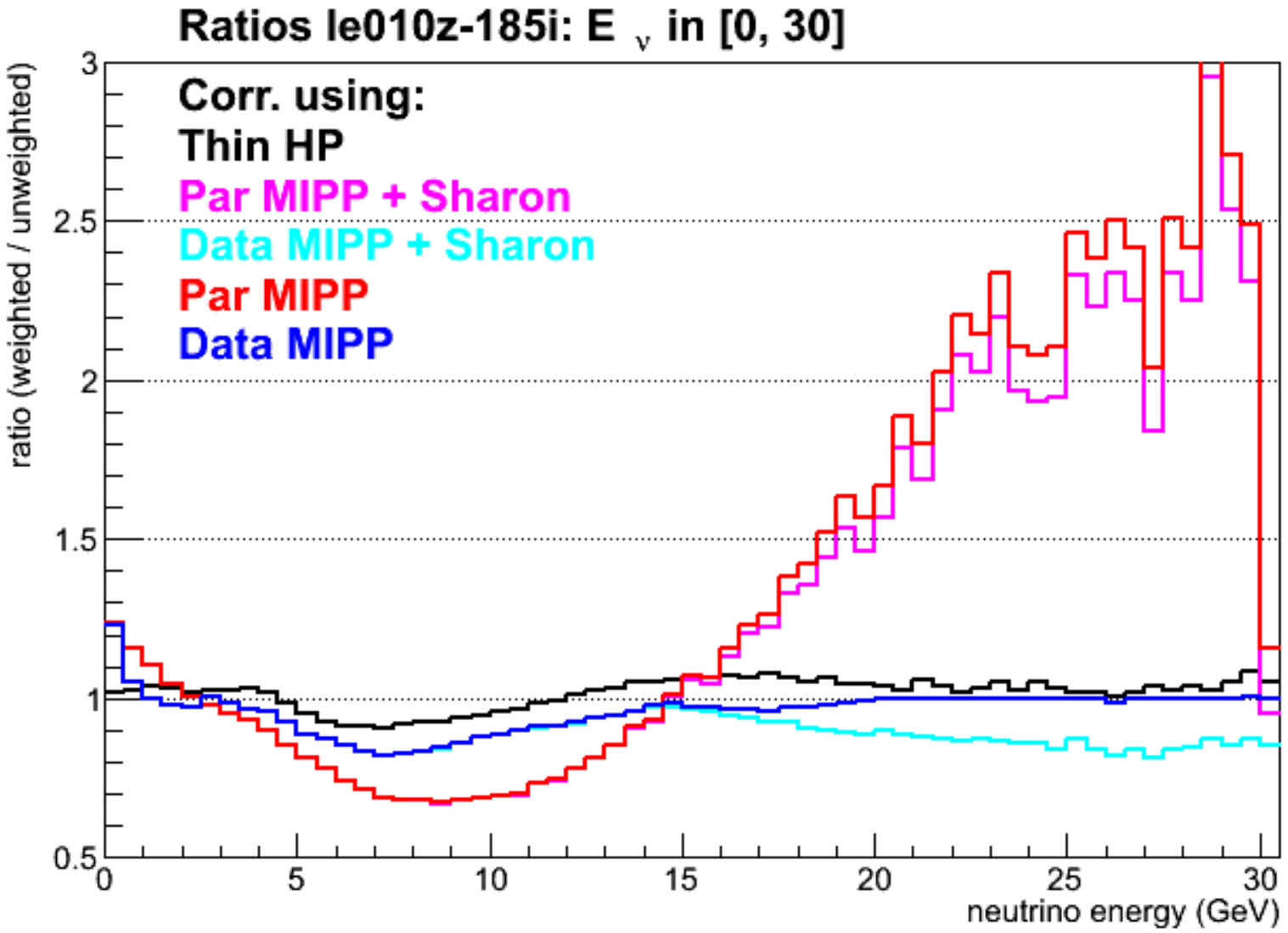




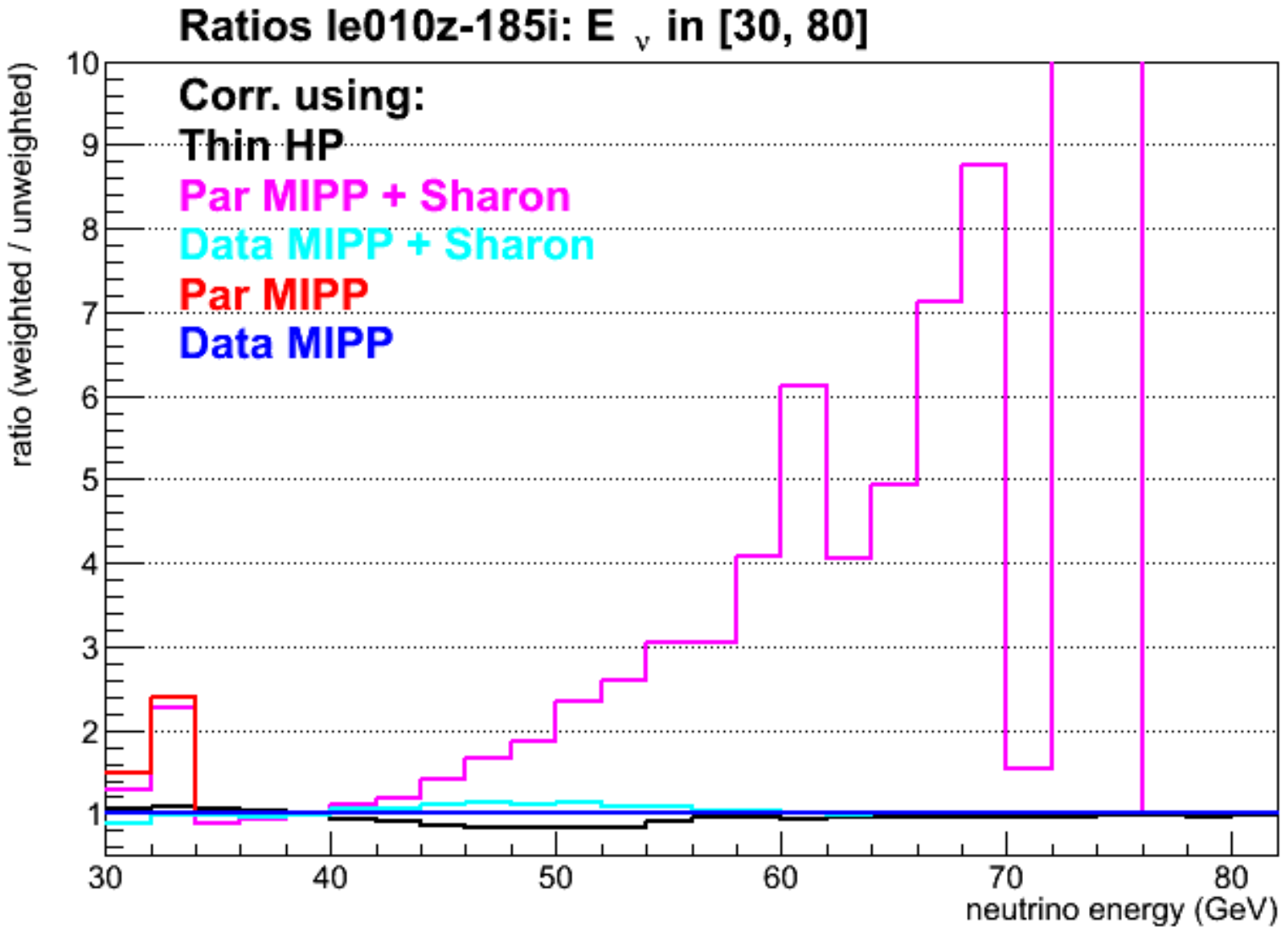




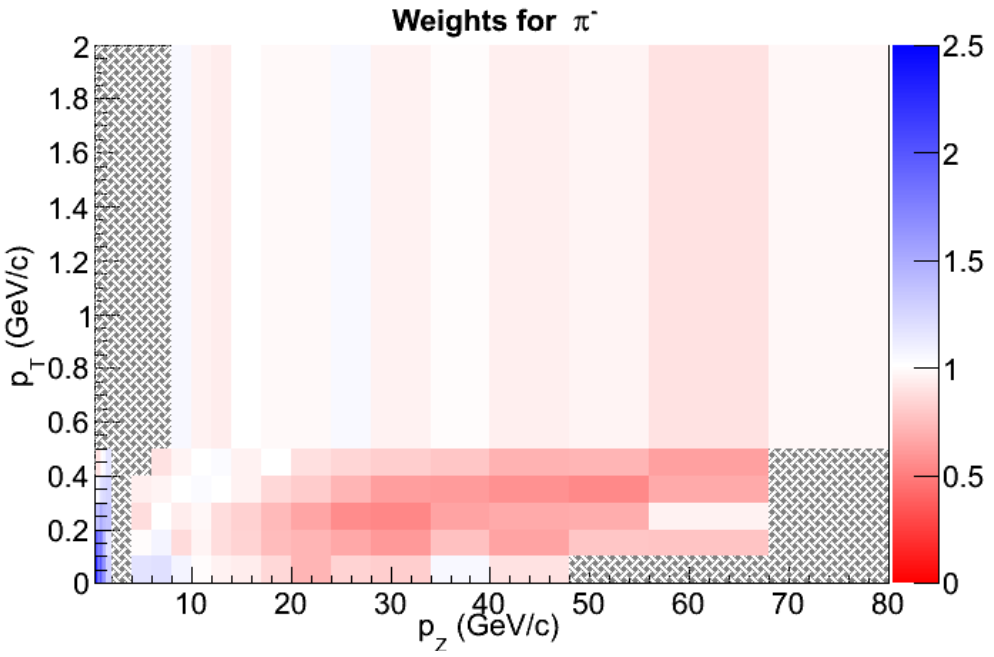
Corrected Flux Over FTFP Prediction
LE RHC

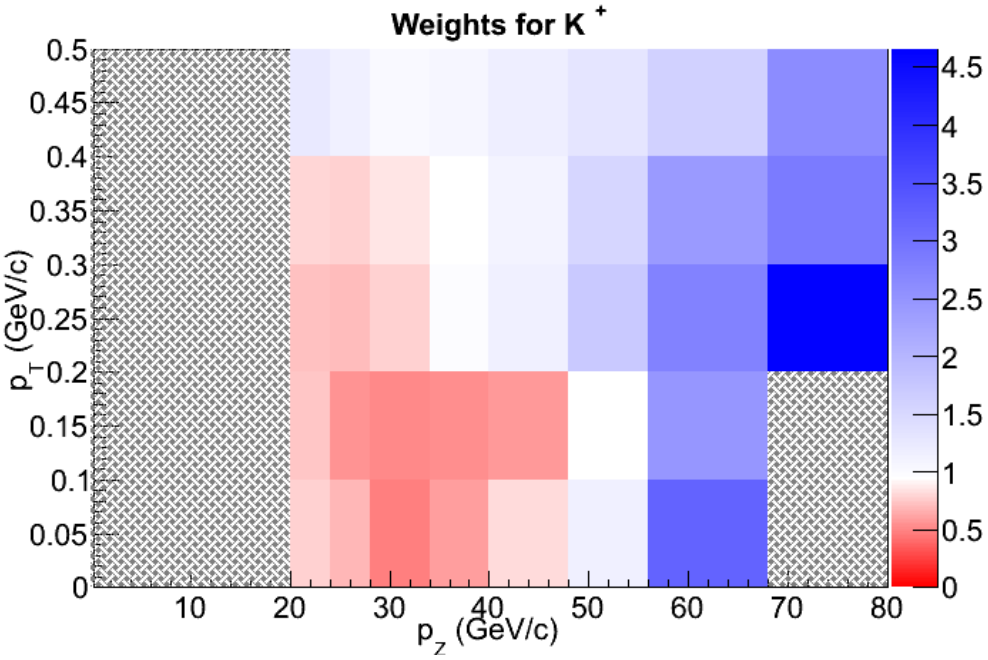


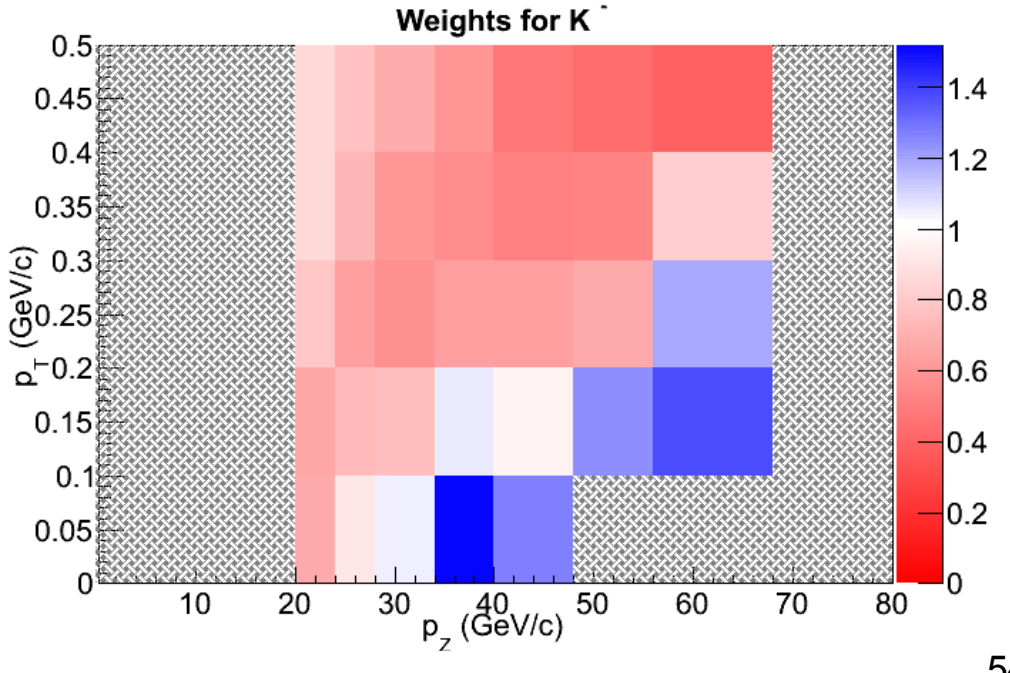
Corrected Flux Over FTFP Prediction
LE RHC

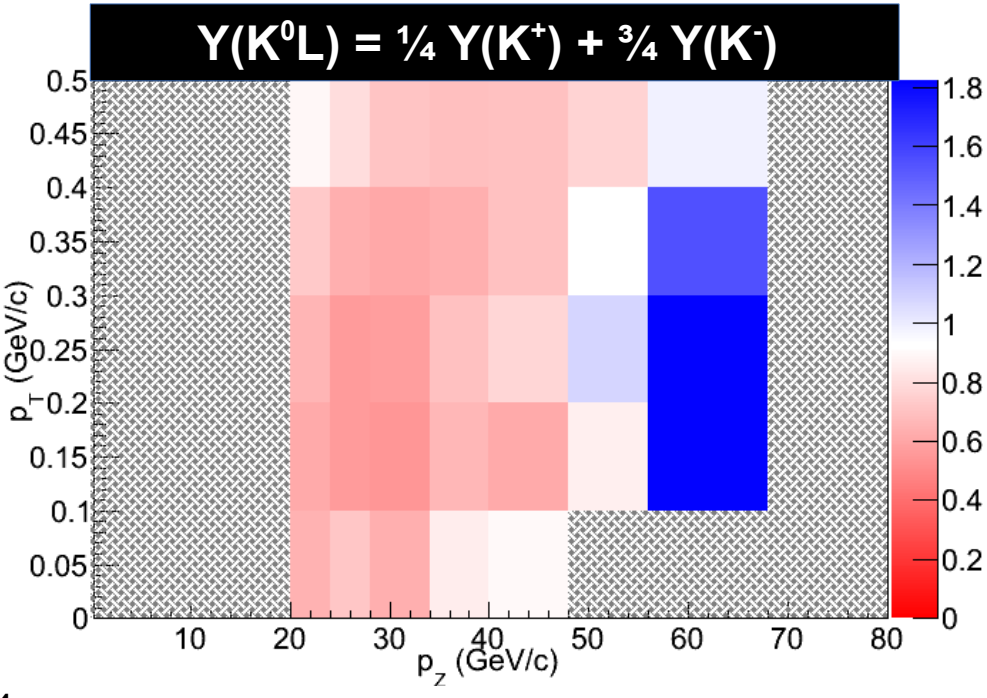


Weight applied from MIPP (no pion plus)









Relevant π^+ yields for LE FHC